1. Overview of the NSTX Upgrade Research Plan for 2014-2018

- 1.1. Introduction
- 1.2. Mission elements of the NSTX-U research program (Menard)
  - 1.2.1. Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)
  - 1.2.2. Develop solutions for plasma-material interface
  - 1.2.3. Advance toroidal confinement physics predictive capability for ITER and beyond
  - 1.2.4. Develop ST as fusion energy system
- 1.3. Unique Parameter Regimes Accessed by NSTX and NSTX-U (Menard + TSGs)
  - **1.3.1. Transport and Turbulence (Ren)**
  - 1.3.2. Macroscopic Stability (Park)
  - 1.3.3. Boundary Physics
    - 1.3.3.1. Pedestal Physics (Diallo, Maingi)
    - 1.3.3.2. SOL physics (Zweben)
    - 1.3.3.3. Divertor physics (Soukhanovskii)
    - 1.3.3.4. High-Z PFC R&D (Maingi, Soukhanovskii)
    - 1.3.3.5. Lithium-based plasma facing component R&D (Jaworski, Skinner)
  - 1.3.4. Energetic Particles (Podesta, Fredrickson, Gorelenkov)
    - 1.3.4.1. *AE instability drive
    - 1.3.4.2. Importance of *AE to NBI
  - 1.3.5. Wave heating and current drive (Taylor, Phillips)
    - 1.3.5.1. High-harmonic fast wave
    - 1.3.5.2. ECH/EBW
  - 1.3.6. Plasma formation and current ramp-up (Raman, Mueller)
  - 1.3.7. Plasma sustainment, advance scenarios and Control (Gerhardt)
- 1.4. Contributions to tokamak physics and ITER (Kaye)
  - 1.4.1. ITPA – physics basis for ITER
  - 1.4.2. Contributions to ITER Design and Operation
- 1.5. Fusion Energy Science Applications of the ST (Menard, Ono)
  - 1.5.1. Development and prototyping of advanced divertor and first-wall solutions
  - 1.5.2. ST-based Fusion Nuclear Science Facility / Component Test Facility
  - 1.5.3. ST-based Pilot Plant
- 1.6. Gaps Between Present and Future STs (Menard)
- 1.7. Summary of Research Goals and Opportunities in NSTX-U (Menard + TSGs)
  - 1.7.1. Overview
  - 1.7.2. Transport and Turbulence
  - 1.7.3. Macroscopic Stability
  - 1.7.4. Boundary Physics
  - 1.7.5. Energetic Particles
  - 1.7.6. Wave heating and current drive
  - 1.7.7. Plasma formation and current ramp-up
  - 1.7.8. Plasma sustainment, advanced scenarios and control
- 1.8. NSTX-U Long-term Goals (Years 5-10) (Menard, Ono, Kaye)
- 1.9. NSTX-U Scientific Organizational Structure (Menard, Kaye)

3. Research Goals and Plans for Transport and Turbulence

3.1. Overview of goals and plans

3.1.1. *Establish predictive capability for the performance of STs/FNSF* (Ren)

3.1.1.1. Identify relevant scenarios

3.1.1.2. Identify most important transport issues (low-k/high-k, ES/EM, NC, *AE, core/ped)

3.1.2. *Thrust 1: Identify mechanisms responsible for thermal, momentum, and particle/impurity transport* (Ren)

3.1.2.1 Motivations: Observed neoclassical ion thermal transport, but anomalous electron thermal, momentum, and particle/impurity transport; clarify limit of ν_* scaling to next generation ST

3.1.2.2. Many theoretical mechanisms to consider for different transport channels:
- Neoclassical: ion thermal, particle/impurity
- Low-k turbulence (ITG/KBM, TEM, microtearing): thermal, momentum and particle/impurity
- High-k turbulence (ETG): electron thermal
- Alfvenic eigenmodes (with EP TSG): electron thermal

3.1.2.2. Mechanism “identification” closely tied to theory
- Diagnostics, experimental tools (flow, current profile control by 2nd NBI and 3D coils) and neoclassical and GK simulations

3.1.3. *Thrust 2: Establish and validate reduced transport models (0D and 1D)* (Guttenfelder, Kaye)

3.1.3.1. Existing 0D scalings and projections (ST/ITER scaling)

3.1.3.2. Predict turbulence and transport scalings from nonlinear simulations for different mechanisms (ITG, TEM, KBM, MT, ETG)

3.1.3.3. Initial predictive results with available transport models (NC, TGLF)

3.2. Research plans

3.2.1 *Thrust 1: Identify mechanisms responsible for thermal, momentum, and particle/impurity transport* (Ren)

3.2.1.1 Neoclassical transport

3.2.1.1.1 Determine if ion thermal, particle, and impurity transport is described by neoclassical
3.2.1.1.2 Identify regimes where discrepancies arise

Near term (Years 1-2)

3.2.1.1.3 Utilize extended BT, Ip, nu
3.2.1.1.4 Use gas puff/ME-SXR for perturbative impurity transport

Long term (Years 3-5)

3.2.1.1.5 Use full range BT, Ip, nu
3.2.1.1.6 Use laser blow-off for perturbative impurity transport
3.2.1.1.7 Investigate with new PFC/divertor conditions

3.2.1.2 Low-k turbulence

3.2.1.2.1 Identify regimes where ion thermal (and electron, momentum, particle/impurity) is anomalous, guided by GK sims (L/H mode, ITB)
3.2.1.2.2 Correlate transport to low-k turbulence (BES, refl., polarimeter)
3.2.1.2.3 Correlate polarimetry with electron transport in high beta microtearing regimes (guided by GK sims)
3.2.1.2.4 Compare turbulence and transport with GK predictions (and synthetic diagnostics)

Near term (Years 1-2)

3.2.1.2.5 Utilize extended BT, Ip, nu
3.2.1.2.6 Use perturbative experiments for momentum transport (2nd NBI, RMP) and impurity transport (gas puff+ME-SXR)
3.2.1.2.7 Use 2nd NBI, RMP coils for q, flow variations

Long term (Years 3-5)

3.2.1.2.8 Use full range Ip, Bt, nu
3.2.1.2.9 Perturbative impurity/cold-pulse experiments with laser blow-off
3.2.1.2.10 Use 2nd NBI, NCC 3D coils for q, flow variations
3.2.1.2.11 Distinguish key parametric dependences of transport and low-k turbulence
3.2.1.2.12 Investigate transport changes with PFC/divertor conditions
3.2.1.2.13 Investigate ρ_* scaling with improved density control ($n \sim \rho_*^{-2}$)

3.2.1.3 High-k turbulence

Near term (Years 1-2)

3.2.1.3.1 Install high-k_θ, prelimineary measurements in ETG dominant regimes (guided by GK sims)

Long term (Years 2-5)

3.2.1.3.2 Correlate high-k_θ turbulence with electron thermal transport

3.2.1.3.3 Identify ETG controlled transport using high-k coupled with GK sims + synthetic diagnostics

3.2.1.3.4 Utilize cold-pulse propagation experiments (w/ laser blow-off, ME-SXR) with high-k to investigate stiffness

3.2.1.4 *AE, fast particle driven thermal transport

Near term (Years 1-2)

3.2.1.4.1 Measure *AE mode structure with calibrated BES/refl. over with range of BT, Ip, nu, PNBI

3.2.1.4.2 Correlate *AE activity with electron thermal transport

Long term (Years 3-5)

3.2.1.4.3 Refine dependence of electron thermal transport with *AE and range of applicability

3.2.1.4.4 Develop/test available reduced models for *AE driven χ_e (w/ EP)

3.2.2. *Thrust 2: Establish and validate reduced transport models (0D and 1D)* (Guttenfelder)

3.2.2.1. Confinement and transport scaling measurements

Near term (Years 1-2)

3.2.2.1.1. Establish 0D confinement scaling at higher B_T, I_p, lower ν_*, initial projections to FNSF/Pilot

3.2.2.1.2. Establish profile database of relevant scenarios for 1D analysis and model validation (I_p, B_T, ν_*, … scans)

Long term (Years 3-5)

3.2.2.1.3. Extend 0D confinement scaling to full range of B_T, I_p, ν_*

3.2.2.1.4. Project 0D performance to FNSF/Pilot

3.2.2.2. Model development and validation

Near term (Years 1-2)

3.2.2.2.1. Predict turbulence and transport scalings from nonlinear simulations for different mechanisms

3.2.2.2.2. Validate TGLF with linear/non-linear simulations for NSTX-U parameters

- 3.2.2.2.2.1. Explore altenative reduced model development (e.g. semi-empirical, “Multi-Mode”, …)

3.2.2.2.3. Test predictions of 0D confinement scaling

3.2.2.2.4. Test profile (1D) predictions for idealized scenarios (e.g. isolated transport mechanisms)
  3.2.2.2.4.1. Neoclassical predictions of Ti (H-modes)
  3.2.2.2.4.2. Neoclassical predictions of part/impurity transport (MIST, NCLASS/NEO)
  3.2.2.2.4.3. ETG predictions of Te (low-beta H-mode; RF)
    3.2.2.2.4.3.1. Coupled flux-tube ETG transport simulations (TGYRO/TRINITY)
  3.2.2.2.4.4. ITG predictions of Ti (L-modes)
3.2.2.2.5. Test predictive models for multiple transport channels (thermal, momentum, particle/impurity) for different scenarios (L, H, RF)
3.2.2.2.6. Test sensitivity to boundary conditions (constrained to ped. scalings)
3.2.2.2.7. Identify where thermal transport models fail, e.g. correlated with energetic particle trends, β_{fi}, $\nabla\beta_{fi}$, …

Long term (Years 3-5)

3.2.2.2.8. Revise TGLF as required for NSTX-U/FNSF/Pilot scenarios (w/ GA)
  3.2.2.2.8.1. More general equilibrium description, ∇P_{eq} ($\kappa/\nabla B$) and $B_{\|}$
  3.2.2.2.8.2. More general basis function expansion (multi-scale of MT)
  3.2.2.2.8.3. Recalibrate QL transport including nonlinear NSTX-U sims
3.2.2.2.9. Incorporate best pedestal models into integrated predictions (w/ BP)
3.2.2.2.10. Incorporate best EP/*AE models into integrated predictions (w/ EP)
3.2.2.2.11. Continue validation with NTSX-U full field plasmas
3.2.2.2.12. 0D and 1D predictions for FNSF/Pilot

3.3 Summary timeline for tool development to achieve research goals

3.3.1 Theory and simulation capabilities (Guttenfelder, Wang, Chang, Hammett, Ren, Poli, Kaye)
  3.3.1.1 Local codes (GYRO, GS2, GENE, GKW) – scaling studies with comprehensive physics\
  3.3.1.2 Global/full-F codes (GYRO, GENE, GTS, XGC-1, Gkeyll) – clarify limits of local and delta-f assumptions, esp. core/pedestal transition
  3.3.1.3 Synthetic diagnostics (BES, high-k, pol., refl., etc…)
  3.3.1.4 Neoclassical theory (NCLASS, NEO, GTC-NEO, XGC0)
  3.3.1.5 Transport models (TLGF; *AE; EPED; …)
  3.3.1.6 Transport solvers (PTRANSP, TYGRO, TRINITY, XPTOR)

3.3.2 Diagnostics (Ren, Smith, Tritz, UCLA(TBD))
  3.3.2.1 New FIR high-k_θ scattering system
  3.3.2.2 Polarimetry system
  3.3.2.3 Additional BES channels
  3.3.2.4 In-vessel multi-energy SXR (ME-SXR) arrays

3.3.3 Other facility capabilities including plasma control (Ren, Tritz, Park, Nova Photonics)

3.3.3.1 2nd NB for q and flow profile control
3.3.3.2 Repetitive laser blow-off impurity injection system
3.3.3.3 NCC for 3D field rotation profile control
3.3.3.4 MSE-LIF for q profile, more XP flexibility (intrinsic rotation)
3.3.3.5 Divertor/PFC/cyro for density control, ρ_* scaling