**Table of contents: Chapter indexing and suggested authors**

**First author listed is responsible for chapter organization, assigning/overseeing sub-chapter co-authorship, and overall completion of chapter**

1. Overview of the NSTX Upgrade Research Plan for 2014-2018
   1. **Menard**, Kaye, Ono, TSG leaders
2. Research Goals and Plans for Macroscopic Stability
   1. **Park**, Berkery, Boozer, Sabbagh, Menard, Gerhardt
3. Research Goals and Plans for Transport and Turbulence
   1. **Ren**, Guttenfelder, Hammett, Kaye, Yuh, Smith
4. Research Goals and Plans for Boundary Physics
   1. **Soukhanovskii**, Diallo, Stotler, Chang, Maingi, Skinner, Jaworski, Canik, Ono
5. Research Goals and Plans for Plasma-Material Interactions and Plasma Facing Components
   1. **Jaworski**, Skinner, Maingi, Ono, Soukhanovskii, Diallo, Stotler, Chang, Canik
6. **Research Goals and Plans for Energetic Particles**
   1. **Podestà, Fredrickson, Gorelenkov, Crocker, Heidbrink, Fu, White, Kramer, Belova, Darrow, Medley, Liu**
7. Research Goals and Plans for Wave Heating and Current Drive
   1. **Taylor**, Hosea, Perkins, Phillips, Bertelli
8. Research Goals and Plans for Plasma Formation and Current Ramp-up
   1. **Raman**, Mueller, Jardin, Taylor, Gerhardt
9. Research Goals and Plans for Plasma Sustainment: Advanced Scenarios and Control
   1. **Gerhardt**, Kolemen, Gates, Mueller, Erikson
10. NSTX-U Facility Status and Proposed Upgrades
    1. **Ono**, Gerhardt, Kaita, Stratton, TSG leaders
11. NSTX-U Collaborator Research Plans by Institution
12. Existing and potential NSTX-U collaborators, edited by **Menard**
13. **Overview of the NSTX Upgrade Research Plan for 2014-2018**
    1. Introduction
    2. Mission elements of the NSTX-U research program (Menard)
       1. Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)
       2. Develop solutions for plasma-material interface
       3. Advance toroidal confinement physics predictive capability for ITER and beyond
       4. Develop ST as fusion energy system
    3. Unique Parameter Regimes Accessed by NSTX and NSTX-U (Menard + TSGs)
       1. Macroscopic Stability (Park)
       2. Transport and Turbulence (Ren)
       3. Boundary Physics
          1. H-mode ped. formation (LH), transport, stability (Kaye, Diallo, Maingi)
          2. SOL physics (Zweben)
          3. Divertor physics (Soukhanovskii)
          4. Particle control
       4. Plasma Material Interactions and Plasma Facing Components
          1. Lithium-based plasma facing component R&D (Jaworski, Skinner)
          2. High-Z PFC R&D (Jaworski, Maingi, Soukhanovskii)
       5. Energetic Particles (**Podestà, Fredrickson, Gorelenkov**)
          1. \*AE instability drive
          2. Fast ion response to \*AE
          3. Importance of \*AE to NBI and combined NBI/HHFW
       6. Wave heating and current drive (Taylor, Phillips)
          1. High-harmonic fast wave
          2. ECH/EBW
       7. Plasma formation and current ramp-up (Raman, Mueller)
       8. Plasma sustainment, advance scenarios and Control (Gerhardt)
    4. Contributions to tokamak physics and ITER (Kaye)
       1. ITPA – physics basis for ITER
       2. Contributions to ITER Design and Operation
    5. Fusion Energy Science Applications of the ST (Menard, Ono)
       1. Development and prototyping of advanced divertor and first-wall solutions
       2. ST-based Fusion Nuclear Science Facility / Component Test Facility
       3. ST-based Pilot Plant
    6. Gaps Between Present and Future STs (Menard)
    7. Summary of Research Goals and Opportunities in NSTX-U (Menard + TSGs)
       1. Overview
       2. Macroscopic Stability
       3. Transport and Turbulence
       4. Boundary Physics
       5. PMI and PFC
       6. Energetic Particles
       7. Wave heating and current drive
       8. Plasma formation and current ramp-up
       9. Plasma sustainment, advanced scenarios and control
    8. NSTX-U Long-term Goals (Years 5-10) (Menard, Ono, Kaye)
    9. NSTX-U Scientific Organizational Structure (Menard, Kaye)
14. **Research Goals and Plans for Energetic Particles**
    1. Overview of goals and plans **[Podestà, Gorelenkov]**
       1. Develop predictive tools for projections of \*AE-induced fast ion transport in FNSF and ITER
       2. Assess requirements for fast-ion phase-space engineering techniques through selective excitation/suppression of \*AE modes
          1. Investigate \*AE dynamics and associated fast ion transport mechanisms
             1. Compare experimental results with theory & numerical codes
          2. Develop physics-based models for \*AE-induced fast ion transport, e.g.:
             1. Stochastic transport models
             2. Quasi-linear models
          3. Assess modifications of \*AE dynamics using NB, HHFW and active \*AE antenna as actuators
    2. Research Plans
       1. **Year 1:**
          1. Compare (classical) TRANSP predictions with FIDA for 2nd NB line
          2. Measure fast-ion transport with tangential FIDA
          3. Measure \*AE eigenfunctions with BES and reflectometers **[Crocker]**
          4. Compare eigenfunctions to predictions performed in FY12-14 **[Crocker]**
          5. Test prototype \*AE antenna **[Fredrickson]**
       2. **Year 2:**
          1. Characterize \*AE activity driven by more tangential 2nd NBI
          2. Compare to existing (more perpendicular) NBI
          3. Use tangential+perpendicular FIDA, NPA/ssNPA to characterize distribution function modifications induced by \*AE modes
          4. Improve NPA analysis tools in TRANSP to include ‘halo’ density
          5. Extend simulations to operations with full 1T magnetic field
          6. Compare measured \*AE damping rates with models & theory **[Fredrickson]**
          7. Characterize scenarios with combined NBI+HHFW (see Wave Heating and CD plans, Sec. 6.2.1.1) **[Taylor, Podestà, Heidbrink]**
       3. **Year 3:**
          1. Extend study of \*AE activity driven by different NBI configurations to full 1T, 2MA scenarios
             1. Extend to non-linear physics and multi-mode physics (coupling between different classes of MHD modes: TAE+kinks, CAE/GAE+TAE, CAE/GAE+kinks)
          2. Compare numerical and theoretical simulations to data on mode dynamics, mode-induced fast ion transport
          3. Optimize \*AE antenna design for efficient coupling to \*AE modes **[Fredrickson]**
          4. Consider replacing 2 HHFW antenna straps with optimized \*AE antenna (with Heating and CD group) **[Taylor, Fredrickson, Podestà]**
          5. Extend simulations of \*AE-induced fast ion transport to FNSF/Pilot
       4. **Year 4:**
          1. Utilize \*AE predictive capability to optimize/minimize \*AE activity during non-inductive current ramp-up with 2nd NBI
          2. Compare simulations to experimental results
          3. Assess performance of upgraded \*AE antenna **[Fredrickson]**
          4. Measure stability of high-*f* \*AEs; assess capability of mode excitation **[Fredrickson]**
       5. **Year 5:**
          1. Assess requirements for "fast-ion phase-space engineering" techniques through selective excitation of \*AE modes **[Podestà, Gorelenkov, Fredrickson]**
          2. Actuators: NBs, HHFW, active \*AE antenna
          3. Extend simulations of \*AE-induced fast ion transport to FNSF/Pilot current ramp-up phase
          4. Assess implications for FNSF/Pilot design (eg: optimum NBI geometry), expected NB-CD
    3. Summary timeline for tool development to achieve research goals
       1. Theory and simulation capabilities
          1. ORBIT - gyro-center particle following **[Podestà, White]**
             1. Stochastic transport by TAEs
          2. SPIRAL - full-orbit particle following **[Kramer]**
             1. Fnb response to kinks, CAE/GAE, TAE modes
             2. Compare with gyro-center simulations w/ ORBIT
          3. NOVA, PEST – ideal MHD **[Gorelenkov]**
             1. (Ideal) mode eigenfunctions
             2. Linear stability/damping rates
          4. HYM – non-linear, hybrid/MHD **[Belova]**
             1. Research goals:

Study excitation of GAE and CAE modes, and their effects on particle confinement **[Belova]**

Detailed comparison with experimental results **[Kramer, Fredrickson, Crocker, Medley]**

* + - * 1. Plans:

Study the effects of the sub-cyclotron modes on fast ion distribution function in NSTX/NSTX-U **[Belova]**

Study the effects of finite frequency (Hall term) on the stability properties of the NBI-driven sub-cyclotron frequency modes **[Belova]**

Effects of GAE modes on the electron transport **[Gorelenkov, Belova]**

Add sources and sinks in the HYM numerical model **[Belova]**

Perform long time scale nonlinear numerical simulations to study the nonlinear evolution of unstable modes **[Belova]**

* + - 1. M3D-K – non-linear, self-consistent **[Fu]**
         1. Add realistic model of Fnb (from NUBEAM/TRANSP)
         2. Full mode dynamics, fast ion transport
      2. Quasi-linear models **[Gorelenkov]**
         1. Fnb response to given set of modes; testing on DIII-D, then NSTX-U
      3. Reduced models to be included in NUBEAM/TRANSP **[Podestà, White]**
         1. Fnb response to given set of modes; testing with NSTX data, then explore possibility of using the model in ‘predictive’ mode with \*AEs from NOVA-K
      4. FIDASIM + Fnb evolving codes (long term: NUBEAM) **[Heidbrink]**
         1. Infer Fnb from set of data (FIDA, NPA, neutrons, …)

* + 1. Diagnostics
       1. Diagnostics under development during NSTX-U Outage period:
          1. Tangential FIDA – complement existing systems
          2. Fusion source profile via charged D-D fusion products – test on MAST in FY13 **[Darrow]**
          3. Fixed sightline E//B NPA – must be re-located **[Medley]**
          4. Upgraded ssNPA **[Liu, Heidbrink]**
          5. \*AE antenna for stability measurements, excitation of \*AE mdoes **[Fredrickson]**
       2. New/upgraded diagnostics **[Podestà with input from diagnosticians]**
          1. BES expansion & increased resolution
          2. Neutron collimator
          3. Profile reflectometry with increased frequency range
          4. FIDA & BES Imaging
          5. Radial polarimetry, currently testing on DIII-D
          6. Toroidally-displaced in-vessel multi-energy DXR arrays
          7. Dual-energy, ultra-fast SXR arrays
          8. VB imaging of \*AE modes
          9. BES passive FIDA view
    2. Other facility capabilities including plasma control
       1. 2nd more tangential NBI to modify fast-ion distribution function
       2. \*AE antenna to study stability of (possibly drive) high-f CAE/GAEs, TAE
          1. Goal: direct measurements of damping rate of stable \*AE modes
          2. Target high-f modes

NSTX-U will have unique capabilities for CAE/GAE studies

Complement JET, MAST data for TAEs

* + - * 1. With upgrades, assess requirements for “phase space engineering” – e.g.: assess capability of driving modes, compare to other actuators such as NBI, HHFW