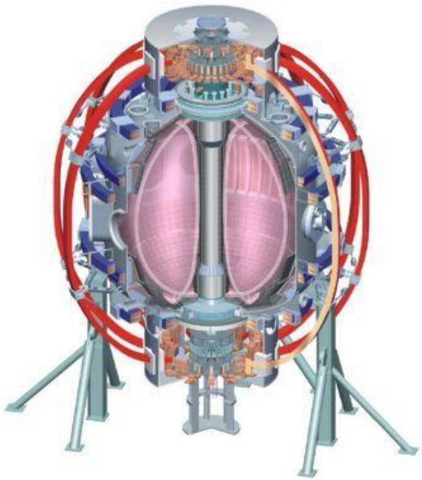
NSTX-U facility enhancement brainstorming meeting: Programmatic Goals and Guidance

J. Menard

for the NSTX Research Team

NSTX-U Facility Brainstorming
B318 - PPPL
February 7-8, 2012

Columbia U
CompX
General Atomics
FIU
INL
Johns Hopkins U
LANL
LLNL
Lodestar
MIT
Nova Photonics
New York U
ORNL
PPPL
Princeton U
Purdue U
SNL
Think Tank, Inc.
UC Davis
UC Irvine
UCLA
UCSD
U Colorado
U Illinois
U Maryland
U Rochester
U Washington
U Wisconsin

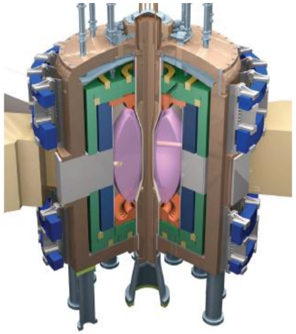


Culham Sci Ctr
U St. Andrews
York U
Chubu U
Fukui U
Hiroshima U
Hyogo U
Kyoto U
Kyushu U
Kyushu Tokai U
NIFS
Niigata U
U Tokyo
JAEA
Hebrew U
Ioffe Inst
RRC Kurchatov Inst
TRINITI
NFRI
KAIST
POSTECH
ASIPP
ENEA, Frascati
CEA, Cadarache
IPP, Jülich
IPP, Garching
ASCR, Czech Rep

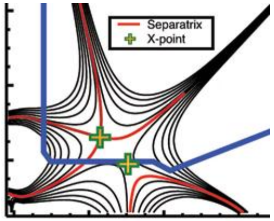
NSTX Upgrade Mission Elements

and associated research goals

- Advance ST as candidate for Fusion Nuclear Science Facility (FNSF)
  - Advance non-inductive start-up, sustainment
  - Develop predictive capability for confinement, high-beta stability, and control
- Develop solutions for PMI
  - Inform FNSF/Pilot/Demo decisions on divertor configurations, high-Z PFCs, Li, cryo-pumping
- Advance toroidal confinement physics for ITER and beyond
  - Utilize waves/HHFW, energetic particles, 3D physics capabilities in support of ITER, beyond
- Develop ST as fusion energy system
  - Integrate + extend performance described above

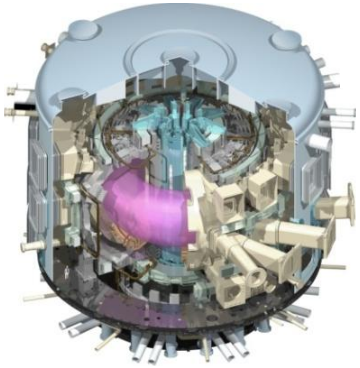


ST-FNSF

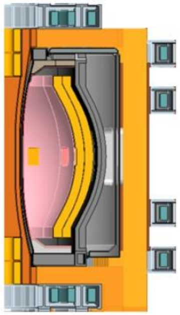


"Snowflake"

Lithium



ITER

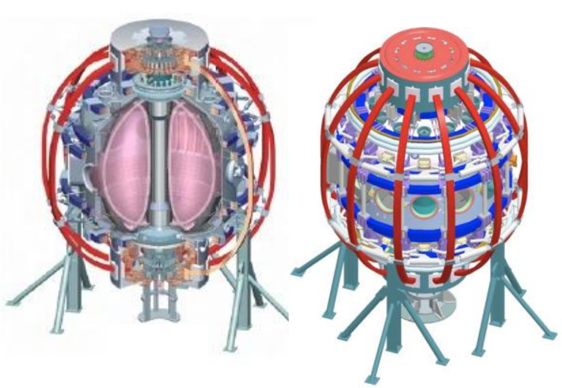


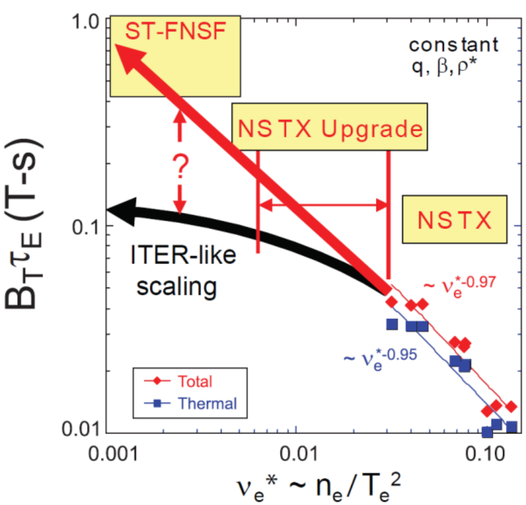
ST Pilot Plant

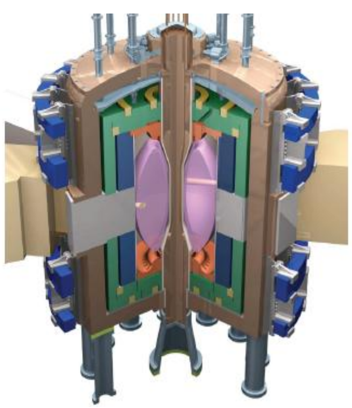
Goal of NSTX Upgrade is provide physics basis for choice of size, power, divertor, operating scenarios of next-step STs

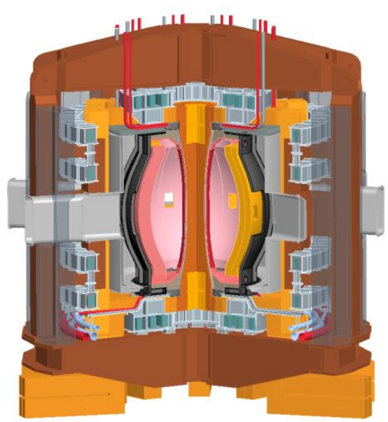
	NSTX	NSTX Upgrade	Fusion Nuclear Science Facility	ST Pilot Plant
Major Radius R_0 [m]	0.86	0.94	1.3	2.2
Aspect Ratio = R_0 / a	≥ 1.3	≥ 1.5	≥ 1.6	≥ 1.7
Plasma Current [MA]	1	2	4 → 10	10 → 20
Toroidal Field [T]	0.5	1	2-3	2-3
P/R, P/S [MW/m,m^2]	10, 0.2*	20, 0.4*	30 → 60, 0.6 → 1.2	40 → 100, 0.3 → 1
Fusion gain Q_{DT}			0 → 1-3	0 → 10-20

** Includes 4MW of high-harmonic fast-wave (HHFW) heating power*









Priorities and Goals

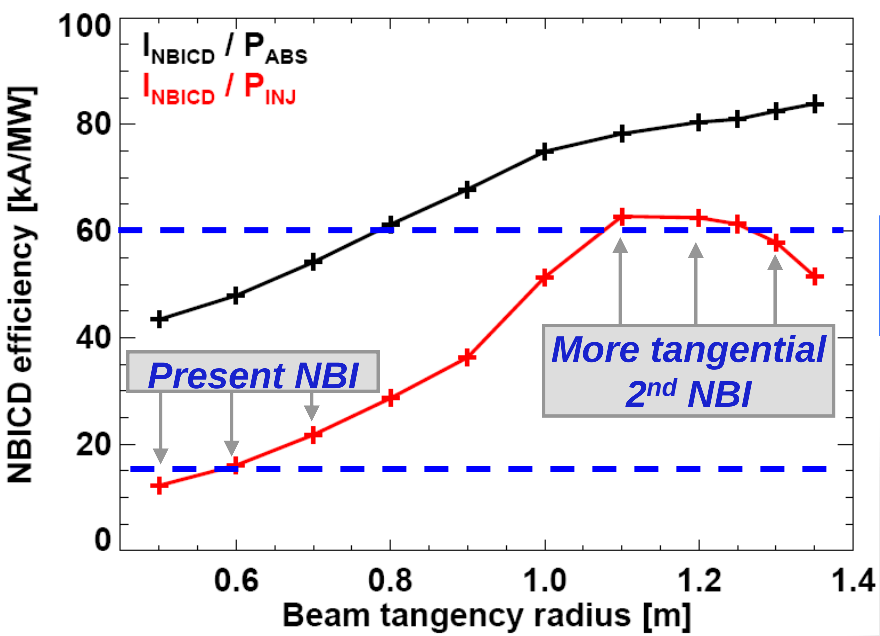
- Overall prioritization (same as Masa's talk)
  1. Successful completion of NSTX Upgrade Project
  2. Enhancements needed for NSTX-U operation
  3. Implement high priority enhancements as resources become available after completion of NSTX-U Project
- The goals that follow are long-range goals
  - To be completed by end of 5 year plan (2018)
  - Viability will be strongly influenced by available resources and NSTX-U experimental results

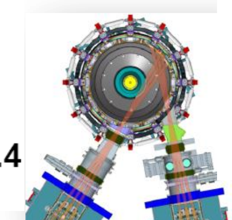
NSTX Upgrade will provide critical test of non-inductive current ramp-up using NBI current drive

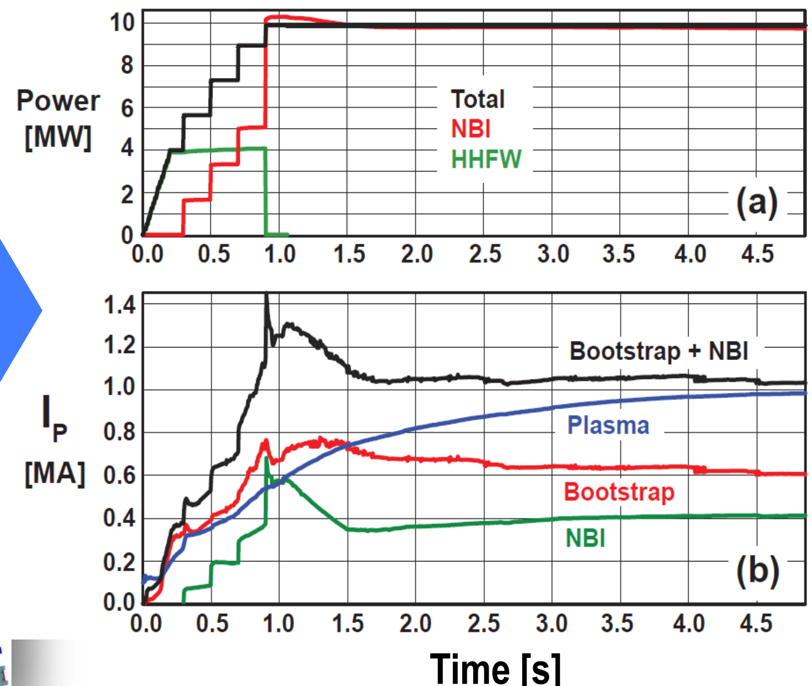
- New CS increases B_T (improves stability) & t_{flat} (for J(r) equilibration)
- More tangential injection provides 3-4x higher CD at low I_P:
  - 2x higher absorption (40→80%) at low I_P = 0.4MA
  - 1.5-2x higher current drive efficiency

E_{NBI}=100keV, I_P=0.40MA, f_{GW}=0.62

$\overline{n}_e = 2.5\times10^{19}m^{-3}$, $\overline{T}_e$ = 0.83keV







NSTX-U non-inductive start-up/ramp-up goals:

- Assess expected favorable scaling of CHI start-up with B_T
  - I_P scales linearly with B_T if higher V_{CHI} realizable (under analysis)
  - Extend/validate recent NIMROD and TSC modeling of CHI
- Test auxiliary heating and CD of CHI-formed plasma
  - Use 2nd NBI, HHFW as planned for FY2011-12, ECH (if available)
- Assess NBI ramp-up of low-I_P plasma to higher I_P
  - Model/develop optimized target plasma for NBI ramp-up
  - *AE avalanches, fast-ion redistribution potentially important

NSTX-U transport & turbulence research goals:

- Identify instabilities responsible for anomalous transport (thermal, momentum, and particle/impurity)
  - Measure scaling of local transport with relevant parameters
  - Measure turbulence characteristics (δn_e, δB_r, …) and scaling with parameters: low-k/BES, high-k/μ-wave, δB_r / polarimetry
  - Compare with linear and non-linear predictions to discriminate theoretical modes: k spectra and transport fluxes
- Establish/validate reduced transport models
  - Validate existing 0D confinement scalings: W_{core} and W_{ped}
  - Develop transport models using profile database, analytic fits to linear and non-linear GK simulations, TGLF, neoclassical
  - Validate models w/ profile data from NSTX/NSTX-U, MAST

NSTX-U macroscopic stability research goals:

- Identify & correct possible n=1-3 intrinsic error fields
- Develop validated models of RWM, NTV, and NTM
  - Vary & reduce ν^*, vary fast ion anisotropy using 2nd NBI
- Develop simultaneous control of β_N, RWM, $\Omega_\phi(r,t)$, q(r,t)
- Extend models/validation of plasma response to 3D fields
- Design, implement off-midplane 3D control coils
  - What are new/unique applications of such coils?
- Disruptions:
  - Test/optimize MGI: vary injection position, magnitude, gas
  - Identify precursors, measure disruption forces, assess avoidance
  - Relate kink stability of quenching plasmas to halo characteristics

NSTX-U boundary physics research goals:

- Investigate pedestal/SOL profiles/width, transport, and turbulence at higher B_T, I_P, P_{SOL}, reduced ν^*
- Develop, utilize snowflake divertor + real-time divertor fueling/detachment for heat-flux mitigation and control
  - Real-time multi-x-point ID, divertor temperature and P_{RAD}
- Measurements, modeling, mitigation of edge impurity sources and transport (XGC0 kinetic-neoclassical promising…)
- Design, implement cryo-pumps for D particle control
  - Provide particle pumping for scenarios w/o Li, compare to Li
- Understand, utilize advanced pedestal operating modes:
  - 'Enhanced Pedestal' H-mode, I-mode, ELM triggering with 3D δB
  - Test edge particle control w/ externally applied fields/driven EHOs

NSTX-U lithium and PFC research goals:

- Assess inboard and outboard divertor Mo PFCs as improved substrate for evaporated Li for particle control
  - If favorable, design and install high-Z PFCs for outboard walls + assess, design, implement hot wall (using bake-out) capability
- Test Li coatings for pumping longer τ_{pulse} NSTX-U plasmas
  - Assess D pumping vs. surface conditions (MAPP), PFC spectroscopy
  - Work w/ LTX to understand Li chemistry, impact of T_{wall}, Li thickness
  - Design/develop methods to increase Li coating coverage: evaporation into neutral gas, upward LiTER, Li paint sprayer
  - Assess impact of full Li wall coverage on pumping, confinement
- Develop, assess liquid Li for divertor heat-flux mitigation
  - Options: flowing Li film/jet/trenches, capillary porous system
  - Assess D/other pumping capability of these systems

NSTX-U energetic particle, wave physics, and scenario development goals:

- Measure and model fast-ion transport and loss
  - Tangential + perp. FIDA, *AE eigenfunctions: BES, reflectometers
  - Assess impact of 2^{nd} more tangential NBI on fast-ion-driven MHD
  - Linear/non-linear simulations (NOVA,M3D) of *AE, fast-ion x-port
  - Utilize AE antenna(e) to measure *AE damping rates, drive *AE
- HHFW – assess performance in Upgrade: higher B_T, I_P, n_e
  - Heat CHI start-up plasma coupled to induction and/or ECH
  - Sustain low I_P plasma 100% non-inductively for NBI ramp-up
  - Improve coupling to NBI-heated H-mode for advanced scenarios
- Scenario development will focus on 3 thrusts:

(1) 100% non-inductive, (2) rotation + q profile control, (3) high-I_P for low ν^*

  - Utilize time-dependent scenario modeling, advanced control
  - Extensive hardware & algorithm development needed (will not repeat here)

Guidance for idea submission and presentations

- Primary goal is to develop physics basis for steady-state high-performance ST for FNS applications
  - PMI/PFC innovation, ITER support, ST for fusion energy also important
- Ideas and presentations should emphasize facility enhancements that could possibly lead to:
  - New scientific breakthroughs
  - New predictive understanding/capabilities
  - New operational scenarios
  - Resolution of issues critical to the success of ITER, beyond
- Goal of brainstorming meeting is to get all ideas on the table for discussion and consideration
  - Will need to prioritize, time/stage enhancements based on:
    - Cost and schedule, likely overall benefit to research program
    - Anticipated capabilities/upgrades of other facilities