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NSTX Program Overview

Exciting Plasma Science
⇒ Effective MFE Development

Martin Peng

NSTX Research Forum 2002

November 28-30, 2001
PPPL
Princeton, NJ

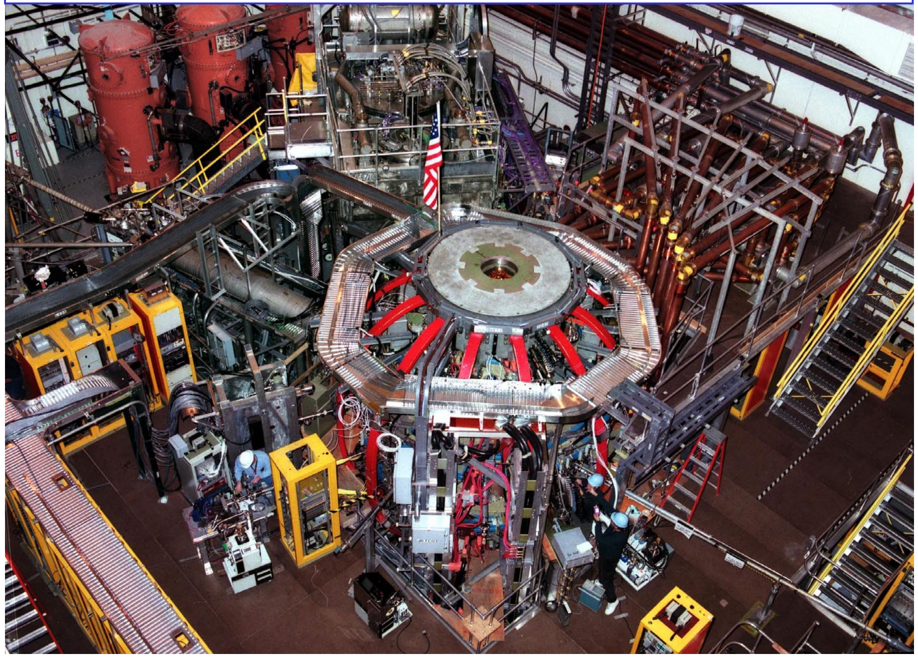
Proof of Principle Mission for ST as an ICC

NSTX

FESAC (1999)

- Develop broad understanding of all basic physics principles
- Carry out comprehensive plasma measurements
- Address critical technology feasibility issues
- Verify agreement between experiments and theory
- Explore concept variation, innovation, and optimization
- Enable evaluation of fusion energy potential
- Produce basis for Performance Extension exp.

National Spherical Torus Experiment



Working together with

- Japan: TST-2, HIST, TS-3, TS-4
- R.F.: Globus-M
- U.K.: MAST
- U.S.: Pegasus, HIT-II, CDX-U

NSTX National Research Team & International Cooperation

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Korea, KBSI: N. Na **(K-Star Cooperation)**

*In cooperation with DOE OFES Theory, OFES Technology, Astrophysics, or SBIR programs

ST Research Addresses a New Range of Parameters

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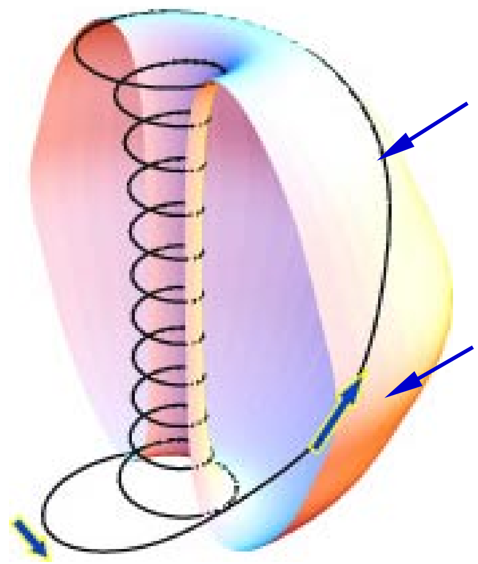
ST Magnetic Configuration



Goal: Investigate and understand the effects of very low A:

- Very strong shaping:
  $A \geq 1.26$, $\kappa \leq 2.5$, $q_{edge} \sim 10$
- Large β_T ($\leq$ 40%) & central β_0 (~100%)
- High f_{BS} ($\leq$ 70%) & B_p/B_t (~1)
- Large Alfvén number & shear (~10^6/s)
- Supra-Alfvénic fast ions (v_{fast}/v_A ~4); large ρ^* (~30–50)
- High dielectric constant:
  $\varepsilon = (\omega_{pe}/\omega_{ce})^2 \sim 30\text{-}100$
- Large SOL magnetic mirror ratio ≤ 4

Research also:

- Builds on and broadens understanding of toroidal plasmas
- Enhances predictive capabilities
- Potentially leads to attractive energy producing devices in future

ST Parameter Range Defines Outstanding Scientific Questions of Very High β and Strong Shaping

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- Can limiting macroscopic instabilities be stabilized at very high β_T and central β, and strong plasma shaping and flow?
- Are turbulence-induced transport reduced by large plasma flow shearing rate and large ion orbit sizes in such plasmas?
- How do radiofrequency waves (sub-, trans-, and high-harmonic ion cyclotron, and electron cyclotron ranges) interact with plasmas of high dielectric constant (ε >>1) differently from plasmas of $\varepsilon \sim 1$?
- How do supra-Alfvénic fast ions drive MHD modes (incl. magnetic sonic waves) unstable to saturation differently from trans-Alfvénic fast ions?
- How do very large mirror ratios of the axisymmetric Scrape-Off Layer affect the edge plasma properties and plasma-material interactions?
- How do symmetry-breaking instabilities and magnetic reconnection intervene between regions of open and closed, current-carrying, nearly axisymmetric field lines?

ST Plasmas Provide Laboratory Test Bed for Naturally Occurring High β Plasmas

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- Plasma micro-turbulence and energy transport in β~1 plasmas ⇔ **cooling of accretion disc plasmas near a black hole**?
- Excitation of sub-harmonic Toroidal Alfvén Eigenmodes and trans-harmonic Compressional Alfvén Eigenmodes (CAE) by supra-Alfvénic beam ions ⇔ **whistler and magnetosonic wave excitation in the magnetosphere**?
- Possible stochastic ion heating by CAE in NSTX ⇔ **nonlinear magnetosonic wave heating of ions in solar corona**?
- Magnetic reconnection observed in helicity injected ST plasmas ⇔ **solar corona eruptions and other disruptive plasma events in space**?
- Efficient electron heating by high-harmonic magnetosonic waves in NSTX ⇔ **electron heating in solar wind**?
- Moderate to high Z spectral lines observed in high-temperature plasmas ⇔ **atomic physics of stellar plasmas**?

MHD & Transport and Current Drive & Edge Physics Receive Equal Emphasis in NSTX Research

NSTX

	Noninductive Assisted			Noninductive Sustained
FY	2001	2002	2003	2004 - 2006
Expwks	15	13(12)	13+	40

ST MHD & Transport Physics for $\tau_{skin} \gg \tau_{pulse} \gg \tau_E$, $\beta_T \leq 25\%$

ST Current Drive & Edge Physics for $\tau_{skin} \gg \tau_{pulse} \gg \tau_E$, $\beta_T \leq 25\%$

ST Physics for $\tau_{pulse} > \tau_{skin}$, $\beta_T \leq 40\%$

FY01-03 Research Milestones (IPPA Implementation Approaches)

- Study τ_E
- Heat with HHFW
- Study MHD modes (no feedback)
- Assess effects of high β_T & flow on χ
- Test CHI startup (Interim) ⟺ Demonstrate CHI startup
- Test HHFW current drive efficiency (Interim) ⟺ Assess HHFW current drive efficiency
- Study SOL fluxes
- Integrate high β_T & high τ_E for ~$5\tau_E$
- Extend startup & sustainment to ~1s

Draft Update

2004 – 2006 Program Areas

- Solenoid-less startup
- Noninductive sustainment
- Heating, CD, BS current prof. control
- MHD mode control
- Turbulence suppression
- Supra-Alfvénic fast ion effects
- Multi-state interface control

Modern Diagnostics Have Been Commissioned to Enable Key Measurements (incl. Collaborations)

NSTX

	FY01	FY02	FY03
Experimental Run-Weeks	7; 8	12	13
MPTS	• 60 Hz, 10 Ch	• 20 Ch	30 Ch •
CHERS	• Tor 18 Ch	• Pol edge	Pol design, Tor 70 Ch •
MSE (Nova)			• CIF 2 Ch •10 Ch • LIF support
FIReTIP (UCD)	• 2 Ch	• 4 Ch	7 Ch •
MHD Modes	• 6 Compensated loops	• Dynamo scanning probe head	
USXR (JHU)	• 3 Pol fans • Mirror array	• Pol fan at 2nd tor position • Higher density top arrays	
Hi-Freq Mirnov	• 3 ch	• 7 ch • GEM X-ray imaging (Frascati/JHU)	
Particle Detectors	• Fixed sightline NPA • Faraday loss probe • Neutrons	• 2-D scanning NPA • E & angle-resolving loss probe	
Fluctuations	• Core reflect. (UCLA) • Edge reflect. (ORNL) • Gas puff imaging (LANL)	• Correlational reflect. (UCLA) • Fast scanning edge probe (UCSD) • MHz gas puff imaging (PSI-SBIR, LANL)	
Divertor Physics Spectroscopy	• Hα 1D CCD (ORNL) • Div. IR cam. (ORNL)	• 2nd CCD	• Visible Bremsstrahlung array • Divertor bolometer • X-ray crystal (Space Sci)
Cameras	• HHFW antenna IR • 2nd fast visible (LANL)	• Add. IR • Fast div. visible (Hiroshima U)	

Major NSTX Experimental Capabilities Plan (•) and Decision Points (♦) Support the Research Milestones

	FY01	FY02	FY03
Experimental Run-Weeks	7; 8	12	13
NBI	• 5 MW; • Add. source		• β feedback
HHFW	• 6 MW (k = 14/m)	• 6 MW (k = 7/m)	• Real-Time φ control
CHI	• I_{inj} = 50 kA	• Absorber design	• Installation
EBW	• Emission-conversion meas.	• 0.4 MW design, integration; ♦ System Decision	♦ FDR
Wall Conditioning Pwr & Part. Cntrl.	• Gas B-zation; • Plasma B-zation	• Hi-temp bake	• Li/B pellet injector; ♦ Long-pulse upgrade
Fueling	• Gas puff, NBI	• Inboard gas fueling	
RWM Control	• Mode ID	♦ System decision	♦ FDR
NTM Control	• Mode ID	• Mode avoidance	♦ EBW & profile requirements
Locked Mode Coil	• Installation; • Error ID	• PF5 error correction	
Plasma Control	• Skybolt-II on-line	• 150 Inputs, GIS Control	

ST Research Aims to Answer Key Fusion Plasma Science Questions for Effective Energy Development

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ST Fusion Plasma Science Questions	⇒	Effective Energy Development
(I) Startup & sustainment with minimal or no solenoid magnet?	⇒	Simplified magnets & device design
(II) High toroidal beta & order-unity central beta?	⇒	Lowered magnet and device costs
(III) Reduce turbulence & improve containment efficiency?	⇒	Smaller unit size for sustained burn
(IV) Wave-energetic particle interaction with over-dense plasma?	⇒	More efficient fusion & RF heating, & CD
(V) Disperse plasma heat and particle fluxes over large area?	⇒	Survivable plasma facing components

Consistent with the overarching goals of ICC research, An attractive element of FES Program.

Rapid Physics Progress Has Raised Interest In A Cost-Effective Performance Extension Next Step ST

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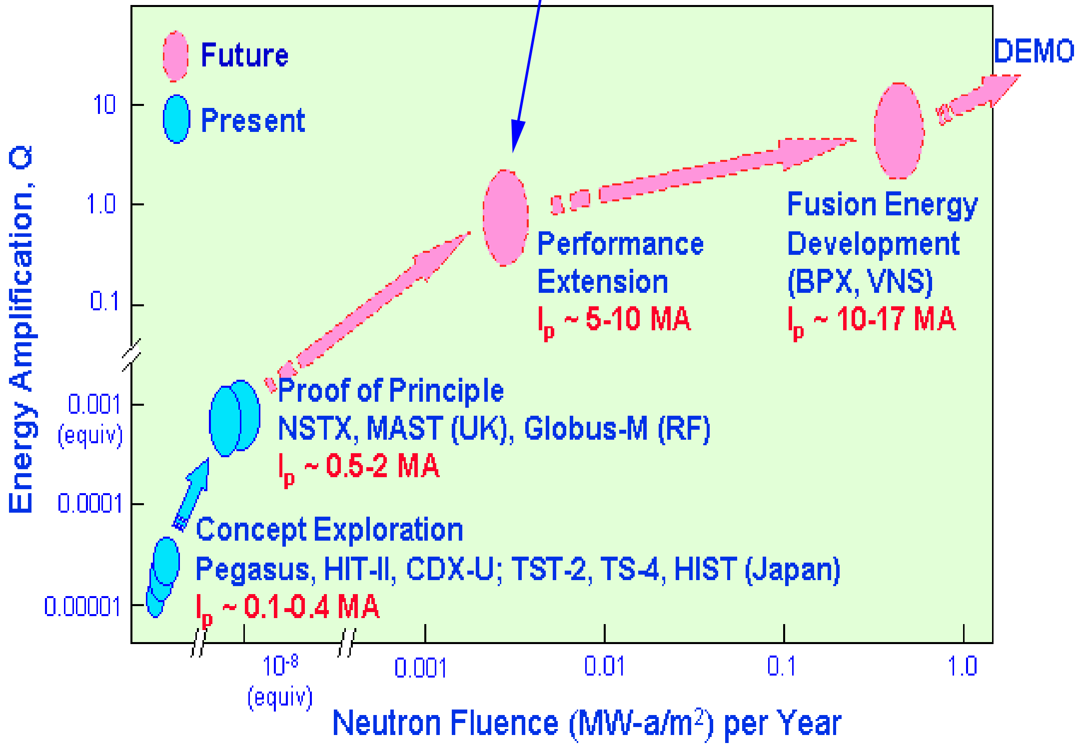
Performance Extension Mission (FESAC 1999)

- Explore physics at or near fusion-relevant absolute parameters
- Achieve dimensionless parameters approaching fusion power system
- Deploy various auxiliary systems for control and optimization
- Provide extensive diagnostics with thorough coverage in space & time
- Integrate physics and technology elements into single demonstration
- Provide a predictive capability via theory and modeling
- Generate sufficient confidence in achieving parameters needed to develop fusion at reasonable cost

A nationally based program with broad international cooperation



PE NSST Program Mission Addresses the ST Fusion Plasma Science Questions and Adds New Database

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- Develop solenoid-less plasma startup physics and techniques to multi-MA level, as envisioned in ST VNS and ARIES-ST (also ARIES-AT)
- Explore plasma physics and techniques of noninductive sustained operation at medium current range (~5 MA), as envisioned in ST VNS and ARIES-ST (also ARIES-AT)
- Contribute at fusion reactor parameters to the MFE science database, using plasmas with strongly shaped (including toroidicity), high beta toroidal (order unity central beta), and over-dense plasmas with large flow (5-10 MA)
- Test D-T plasma performance at high current range (~10 MA) in pulsed operation to access the supra-Alfvénic fusion α heating regime
- Produce sufficient database for future devices, when combined with ITER (or a Tokamak BPX), for physics optimization of Fusion DEMO; and for ST Fusion Energy Development devices (such as BPX, VNS)

The PE NSST Mission Defines Key Scientific Database Needed from the Present ST Research (1)

- Solenoid-less startup
  - Can CHI produce useful plasma targets?
  - Can EBW, HHFW, NBI, BS combine to startup plasma to full current?
- Noninductive sustainment
  - Can high β_T and f_{BS} be maintained for time scales >> τ-current penetration?
  - Can combined RF (EBW, HHFW) and NBI heating and current drive sustain profiles compatible with high β_T, high f_{BS}, and good confinement?
- MFE science database
  - How do strong shaping, high β_T, and large plasma flow affect plasma L-H transition and ITB?
  - Under what conditions can plasma ions approach neoclassical behavior while plasma electrons limit heat loss?
  - Can RWM and NTM be avoided or stabilized if necessary?
  - What ranges of aspect ratio, safety factor, and elongation offer the best opportunities to avoid plasma disruptions?

The PE NSST Mission Defines Key Scientific Database Needed from the Present ST Research (2)

- MFE science database (continued)
  - Can HHFW and EBW provide reliable heating and current drive in over-dense plasmas?
  - Can edge heat flux be dispersed adequately under high power for sustained durations?
- Supra-Alfvénic D-T fusion heating regime
  - What are the conditions under which high confinement and T_i are obtained using supra-Alfvénic NBI heating?
  - What spectrum of CAE frequencies are excited by supra-Alfvénic ions, and how does the "sea" of CAE interact with the thermal ions and electrons?
- Database for future devices
  - What is the integrated physics understanding of axisymmetric configurations, across the entire range of ST-Tokamak parameter space:
    - shaping (A, κ, q), β, f_{BS}, B_p/B_T, Alfven number, flow shear,
    - v_{fast}/v_A, ρ^*, dielectric constant, SOL mirror ratio?

ST Research Offers Exciting Scientific Opportunities That Lead to Effective MFE Development

NSTX

- ST is an ICC at the PoP level, with strong national Team and international cooperation
- Present research addresses new parameter ranges that define outstanding scientific questions of very high β and strong shaping
- MHD & Transport and Current Drive & Edge Physics receive equal emphasis in NSTX research milestones
- Diagnostics and experimental capabilities plans support these milestones
- ST research answers key fusion plasma science questions for effective energy development
- Rapid progress have raised interest in PE NSST, which aims to complement ITER (or a Tokamak BPX) in optimization of DEMO
- PE NSST program mission defines database needed from present ST research

Forum presentations and discussions will help make all this a reality!