Chapter 7

The NSTX National Research Program

The NSTX National Research Program is carried out by a broadly based research team, which has grown since the start of NSTX experimental operations in FY 2000. The collaborative NSTX research has made great strides in advancing the innovative confinement concept research in Fusion Energy Sciences. The management of the NSTX National Research Program is marked by its initial success in bringing a very diverse range of expertise from many institutions of the U.S. fusion community to bear on the challenging and exciting proof-of-principle research on NSTX. The NSTX National Research Program will continue to grow in breadth and effectiveness.

7.1 Introduction

Research on NSTX is carried out by a National Team of research groups from 17 universities, national laboratories (including PPPL), and private industry, most of which participated in the team building effort since FY 1998 to obtain direct collaboration funding from DOE. About 45% of the NSTX scientific personnel in full time equivalent (FTE) including graduate students are from these collaborating institutions. The contributions of the national collaborative team have been extensive, and are accounted in the 5-year plan. The work plans of the collaborating research are identified in Section 7.4 with detail in Appendix to provide supporting information to the NSTX 5-year plan.

Active research users of NSTX total 150 in number including graduate students, consisting of 75 from the U.S. collaborating institutions, 52 from PPPL, and 23 from other institutions in U.S. and the world. A total of 87 engineers and technicians in full time equivalent supported the operation, maintenance, and upgrade of the NSTX facility and the diagnostics systems. The entire NSTX research and facility team have worked together effectively to enable rapid progress toward the proof-of-principle mission of NSTX, since the beginning of experimental research in FY 2000.

The management of this diverse group of scientists and their research activities, in concert with the supporting activities by the NSTX facility operations team, is an important part of NSTX National Team effort and the NSTX 5-year plan.

In the following we present a brief summary, as supporting information, of the effort that built the new NSTX national research team during FY 1998-2000 (Section 7.2); the continued process of working together effectively since then to carry out national team research and planning, and to build a growing NSTX national research team (Section 7.3); the collaborations' research plans (Section 7.4); other important cooperative research activities within the U.S. fusion community and with fusion efforts in other countries (Section 7.5), and the directions in which to continue enhancing and broadening the NSTX collaborative research in support of the NSTX mission and the Fusion Energy Sciences' program in U.S. and the world (Section 7.6).

7.2 Building a New National Research Team

The foundation of the NSTX National Research Team was built during FY 1997-1998, when interested research groups in the U.S. (including PPPL) were invited to participate in the first two NSTX Research Forums. The goals of the research forums were to

- present to the broad fusion community the exciting opportunities and priorities of the NSTX research program and the supporting capabilities in NSTX facility and operation, and
- solicit the prospective research team members to present and discuss experimental and modeling research ideas of interest, as key input to the formulation of an integrated NSTX national research program plan.

The initial NSTX research program plan was produced in 1998 and became a key reference for the collaboration proposals submitted to DOE by a large number (45) fusion research institutions and groups. Following an extensive peer-review of these proposals, DOE awarded in 1999 funding for three years to 17 groups from 13 U.S. research institutions to join the PPPL researchers to form the new NSTX national research team, which began its activities in FY 1999. Collaboration funding constituted about one-third of the total science research funding for NSTX.

The NSTX Program Advisory Committee (PAC), which was formed in FY 1997 by the PPPL Director, reviewed and provided advice on the priorities of the initial NSTX research program and facility capabilities, as well as the relative emphasis of collaboration's research within the NSTX research program. The resulting research priorities and collaboration emphases were transmitted by the PPPL Director to DOE as reference information for the selection of excellent research groups with highly complementary research expertise and capabilities. A description the NSTX PAC is provided in Section 7.3.

PPPL and on-site NSTX researchers served, beginning in FY 1998, as research contacts for the prospective collaborators, to assist in the preparation of potential collaborator's proposals to DOE. This integrated the prospective proposals into the NSTX research and facility plans, and enabling improved estimates of the costs required to support the proposed research activities and address issues of resource allocation such as port space. Records of Discussion (RoD) were produced jointly by the collaborators

and the research contacts to provide valuable information for the peer-reviewers and DOE in the process of evaluation and decision. The RoD process has continued in support of all NSTX collaboration proposals to DOE.

The collaboration efforts continued modest growth during FY 2001-2002, as additional needs in research capabilities emerged in the community and were identified by DOE and the NSTX research program. DOE further developed a process beginning in FY 2002 to make a transition from the simultaneous review and renewal of all collaboration research every three years, to reviewing about one-third of the collaboration effort each year. This transition is to be completed in FY 2004.

These steps of concerted outreach, organization, and planning activities have led to the creation of an NSTX national research team of exceptional quality, which contributed to the rapid and extensive initial research success achieved by NSTX during FY 2000-2003. The key results of the NSTX research team are described as part of the 5-year plan in Chapter 3.

7.3 Working Together to Advance NSTX Research

The new collaborative research team, together with cooperative participants in NSTX research who are funded by other programs within OFES or by fusion efforts in other countries, has since FY 2000 grown to 150 in number. Among these 75 are from the collaborating institutions, 52 from PPPL, 23 take part in the cooperative research activities. A total of 36 U.S. and world fusion research institutions and groups are participating in NSTX research activities through these scientific users.

NSTX, with support from PPPL management, has continued its effort to provide a high quality environment for the national team to work in concert to meet the challenges of and take advantage of the opportunities offered by the innovative NSTX Proof of Principle research. The key elements of this national team research management have been:

- A **transparent and participative** process of **annual research planning and review,** leading to **implementation** of detailed experimental activities for each day of experimental operation on NSTX.

- A fully **integrated research team** at all levels of activities with equitable opportunities for team members based on expertise, capability, and performance.

- **Active management of planning and review** of NSTX research and facility operations by the **NSTX Management Team** that reports to the PPPL Director's Office and is in close coordination with the **NSTX Program Advisory Committee (PAC).** This PAC meets twice yearly, as compared with once yearly for the other major U.S. magnetic fusion facilities.

- The preparation of the first **NSTX 5-year plan** involving the entire NSTX research team, which began in June 2002 (one year ago).

7.3.1 Annual research planning, review and implementation – This activity of research team management involves the following steps:

a) The results of the previous experimental campaign are presented in an open forum for review and discussion by the entire research team, to form an updated technical basis to develop the research plan of the next year.

b) The research and facility priorities and leaders of the Experimental Task (ET) groups for the next year are determined by the NSTX management team (see NSTX organization in Fig. 7.1).

c) An annual NSTX Research Forum provides the opportunity for the research team and the interested researchers in the fusion community to propose experiments, as guided by these priorities and organized according to the ET groups.

d) The ET leaders and the Run Coordinator work with team members interested in the ET areas to develop and prepare initial experimental plans based on the results of the research forum. The plans are reviewed and improved by the NSTX management team.

e) The Deputy Program Director recommends experimental run time allocations of the ET areas and other needs, based on the initial plan, for approval by the Program and Project Directors.

f) The research and facility priorities, and research and experimental run plans for the next fiscal year are presented to the NSTX PAC in its September-October meeting for review. The PAC delivers advice on these topics to the PPPL Director in about 2-weeks time. The PPPL Director gives directions to the NSTX management and final approval of the run plan, based on advice from the PAC.

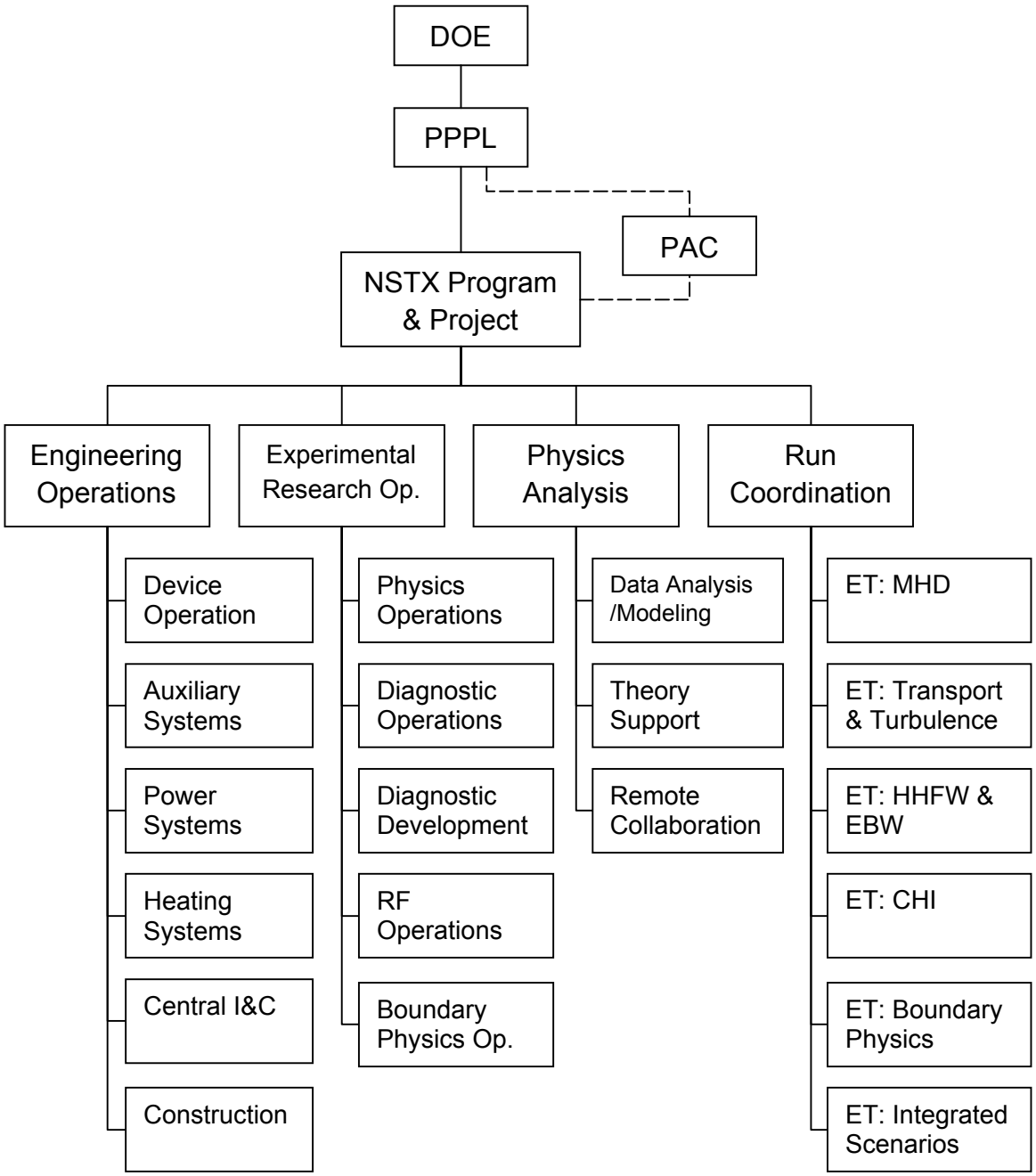

Figure 7.1 NSTX Organization and Management Relationships

g) The Deputy Program Director, working with the Run Coordinator and the ET leaders, implements the run plan.

Contingencies in run time (usually in the range of 15-20% of the total) are built into the initial plan to take advantage of unexpected developments during the fiscal year.

7.3.2 Fully integrated research team – The NSTX research team has been integrated at all levels of the research activities. Each collaboration research topical leader works closely with a research contact who is an onsite member of the NSTX research team with ready access to NSTX support activities. This pairing of researchers of common interest in research topics aims to ensure the success of off-site collaborators by bringing together the diverse research groups effectively to apply the broad spectrum of expertise to the research activities at hand on NSTX. The present collaborator-research contact assignment is provided in Table 7.1 for information.

About one-third of the ET Group leaders and deputies (Fig. 7.1) are selected from the collaboration members every year. Run Coordinator, who is a member of the NSTX Management Team, is selected from the research team each year to coordinate the implementation of the experimental activities among the ET areas. A collaboration researcher successfully served as Run Coordinator during FY 2002, and collaborators are expected to serve in such capacity about one-third of the time. The ET leaders and deputies for FY 2000-2003 are provided in Table 7.2.

Annual selection of the Run Coordinator and Deputy and the ET leaders and deputies, and the full participation by the research team in research planning and implementation, have energized the NSTX research team and led to vibrant and innovative research activities on NSTX. These in turn have contributed much to the rapid progress made so far by the research team in advancing the science of spherical torus fusion-grade plasmas.

7.3.3 Management of NSTX activities – The NSTX Management Team manages the NSTX activities, under the supervision of the PPPL Director's Office and in close coordination with the NSTX PAC (Fig. 7.1).

Table 7.1 NSTX Collaboration Topical Leaders & Research Contacts for FY 2003-2006

Institution	Home-Site Lead	Topical Programmatic Role	Collab. Lead	Onsite Contact
Columbia U	J. Navratil	MHD studies	S. Sabbagh	J. Menard
Comp-X	R. Harvey	RF heating and current drive	R. Harvey	C. Phillips
General Atomics	J. Ferron	CHI equilibrium reconstruction	M. Schaffer	S. Kaye
		RF physics	R. Pinsker	R. Wilson
		Plasma control	J. Ferron	D. Gates
JHU	M. Finkenthal	Ultra-soft X-ray diagnostics	D. Stutman	R. Kaita
LANL	G. Wurden	Fast visible & infrared imaging	R. Maqueda	S. Zweben
	A. Glasser	CHI plasma MHD	X. Tang	R. Raman (UW)
LLNL	G. Porter	Edge, scrape-off layer modeling	G. Porter	R. Maingi (ORNL)
		Boundary stability & turbulence	X. Xu	D. Stotler
Lodestar	D. D'Ippolito	Boundary stability & turbulence	J. Myra	D. Stotler
MIT	M. Porkolab	EBW Modeling	A. Bers, A. Ram	G. Taylor
		HHFW modeling	P. Bonoli	C. Phillips
Nova Photonics	F. Levinton	MSE diagnostics	F. Levinton	D. Johnson
ORNL	D. Rasmussen	RF launcher & experiments	D. Swain	R. Wilson
		ECH/EBW initiation & ramp-up	T. Bigelow	G. Taylor
		Fueling & transport modification	L. Baylor	H. Kugel
	P. Mioduszewski	Edge, H-mode experiments	R. Maingi	V. Soukhanovskii
	D. Batchelor	Transport and RF modeling	W. Houlberg	S. Kaye
UC Davis	N. Luhmann	FIRe-TIP and scattering	K.C. Lee	H. Park
UC Irvine	B. Heidbrink	Fast ion-plasma interactions	B. Heidbrink	D. Darrow
UCLA	T. Peebles	Reflectometry	S. Kubota	T. Munsat
UCSD	F. Najmabadi	HHFW modeling	T. K. Mau	C. Phillips
	J. Boedo	Fast probe	J. Boedo	H. Kugel
	S. Krasheninnikov	Edge intermittent transport	A. Pigarov	R. Maingi (ORNL)
U Washington	T. Jarboe	Coaxial helicity injection	R. Raman	D. Mueller
U Wisconsin	J. Callen	Neoclassical transport modeling	K.C. Shaing	R. Bell

a) NSTX Management Team

Planning, integration, coordination, and review of the diverse range of NSTX research and facility activities are carried out by the NSTX Management team, which consists of the NSTX Program and Project Directors and their Deputies, the Division Heads for Physics Analysis, Experimental Research Operations, and Engineering Operations, and the Run Coordinator.

Table 7.2 NSTX Experimental Task Group Leaders and Deputies for FY 2000-2003

Experimental Task Groups	Leader	Deputy
FY-2000 – RC: M. Bell; Deputy: E. Synakowski		
Ohmic Plasmas	M. Bell	S. Sabbagh (Columbia U)
HHFW Heating	J. R. Wilson	D. Swain (ORNL)
CHI	R. Raman (U Washington)	D. Mueller
FY-2001 – RC: E. Synakowski; Deputy: R. Maingi (ORNL)		
MHD	S. Sabbagh (Columbia U)	J. Menard
Transport & Turbulence	S. Kaye	B. LeBlanc
HHFW	J. R. Wilson	D. Swain (ORNL)
CHI	R. Raman (U Washington)	D. Gates
Boundary Physics	R. Maingi (ORNL)	C. Skinner
FY-2002 – RC: R. Maingi (ORNL); Deputy: S. Kaye		
MHD	J. Menard	E. Fredrickson
Transport & Turbulence	D. Darrow	D. Stutman (JHU)
RF Heating & Current Drive	J. R. Wilson	D. Swain (ORNL)
Non-Inductive Startup	R. Raman (U Washington)	D. Mueller
Boundary Physics	H. Kugel	C. Bush (ORNL)
Integrated Scenarios Development	D. Gates	S. Sabbagh (Columbia U)
FY-2003 – RC: S. Kaye		
MHD	S. Sabbagh (Columbia U)	D. Gates
Transport & Turbulence	B. LeBlanc	D. Darrow
HHFW & EBW	G. Taylor	P. Ryan (ORNL)
CHI	M. Bell	R. Raman (U Washington)
Boundary Physics	H. Kugel	R. Kaita
Integrated Scenarios Development	R. Maingi (ORNL)	J. Menard

Engineering Operations, with its capabilities in device operations, auxiliary, power, and heating systems, central instrumentation & control, and construction, supports the needs of Experimental Research Operations in areas of plasma, diagnostic, RF, and boundary physics operations, as well as diagnostic upgrades. These divisions in turn support the execution of the NSTX experimental run plan carried out by the Run Coordinator and the ET leaders. Physics Analysis, with its capabilities in data analysis and modeling, its coordination of support from PPPL Theory Department, and its facilities to enable remote participation in NSTX experiments and meetings, supports the research investigations required by the planned experiments.

The Program and Project Directors and their Deputies work closely together to manage the multi-faceted research program and facility operations activities on NSTX. These include meeting the DOE/OFES research milestones, updating mission and milestones, developing future national and international collaborations, leading the development of the long-term NSTX/ST program, and representing NSTX in national program interactions (the Program Director); and meeting the DOE/OFES facility and upgrade milestones, operating facility and implementing upgrades to meeting program needs, planning finance, ensuring ES&H success, and overseeing technical interface and support for ongoing collaboration (the Project Director). The Deputy Program Director supports and reports to the Program Director in leading the development of the near-term program plan, leading the discussion of key near-term programmatic decisions and research scenarios, developing proposed ET's, ET leadership, and run time allocations, and coordinating activities of the Division Heads and joint experiments with other facilities. The Deputy Project Director supports and reports to the Project Director in overseeing all engineering and ES&H activities, and serving as liaison to the PPPL Engineering Department.

b) Supervision by PPPL Director's Office

NSTX is a Department within PPPL. The NSTX Program and Project Directors report directly to the PPPL Director's Office. The Director's Office works closely with the NSTX PAC in reviewing and advising on the priorities of the NSTX research program plans, in reviewing the progress, and in rendering advice on new initiatives. The NSTX Department management (the Project Director) carries out the PPPL departmental administrative duties and receives administrative support from PPPL. PPPL management puts very high priority in ensuring that the NSTX research program fulfills

the proof of principle mission of NSTX, and that a broad national research collaboration is fully implemented to carry out state-of-art innovative research on NSTX.

c) NSTX PAC

The NSTX PAC performs a central role in the planning of the research program on NSTX. The PAC is established by the PPPL Director to ensure broad community participation in research planning, experimental operations, data analysis and theory, which has been essential for the success of the NSTX research program. The PAC reviews the progress of the NSTX program and provides advice to the PPPL Director on

- The NSTX experimental research plan including priorities and milestones, consistent with the DOE-approved work scope,
- Major new research initiatives on NSTX to be proposed to DOE, and
- Adjustments to program priorities, taking into account the mission of NSTX and the overall directions of the U.S. and world fusion programs.

The PPPL Director provides guidance to the NSTX research program and facility operations plans in response to the PAC's recommendations.

Members of the PAC also represent the scientific and technical leadership in the fusion community, from major laboratories, universities and industry, including two from foreign institutions. The present members of the PAC are listed in Table 7.3.

The NSTX PAC meets twice annually, typically in January-February and September-October of each year. The January meeting emphasizes a review of the draft NSTX Field Work Proposal, which is to be submitted to DOE in March of each year. The September meeting emphasizes a review of the draft research plan for the new fiscal year. The NSTX PAC, since its formation in FY 1997, has consistently provided high quality insightful advice and made major contributions to the rapid success of the NSTX research program.

The PAC members serve for duration of 4 years; about half of members are new replacements every two years. Previous PAC chair and members, whose names and institutions are provided in Table 7.4 below, have made vitally important contributions to the success of the NSTX.

7.3.4 The NSTX five-year plan – The preparation of the NSTX 5-year plan during the last 12 months has provided a fresh opportunity for the entire NSTX team to develop and project a detailed vision of research and operation to the five-year horizon. Extensive planning and preparation has led to this comprehensive and exciting NSTX 5-year plan presently under review.

- An NSTX 5-Year Research Opportunities Forum was held in June 2002 involving the entire NSTX team and the broader fusion community. The results of this forum provided the basis for the formulation of a draft NSTX 5-year plan by the research team.

Table 7.3. NSTX Program Advisory Committee Members for FY 2003-2004

NSTX PAC Member	Institution
Dr. William Nevins (chair)	Lawrence Livermore National Laboratory
Prof. William Dorland	University of Maryland
Prof. Cary Forest	University of Wisconsin
Dr. Chuck Greenfield	General Atomics
Dr. Martin Greenwald	Massachusetts Institute of Technology
Dr. Mikhail Gryaznevich	Culham Science Center (U.K.)
Prof. Thomas Jarboe	University of Washington
Dr. Mitsuru Kikuchi	Japan Atomic Energy Research Institute
Prof. Gerald Navratil	Columbia University
Dr. Gary Porter	Lawrence Livermore National Laboratory
Dr. David Rasmussen	Oak Ridge National Laboratory
Dr. Mark Tillack	University of California, San Diego
Dr. Michael Ulrickson	Sandia National Laboratory
Prof. James Van Dam	University of Texas at Austin
Dr. Michael Zarnstorff	Princeton Plasma Physics Laboratory
Dr. Masayuki Ono (ex officio)	NSTX Project Director
Dr. Martin Peng (ex officio)	NSTX Program Director (ORNL)

- The draft 5-year plan was presented to the fusion community for feedback in December 2002. The results of this meeting provided a good basis for improving the main emphases of the 5-year plan.

- The improved 5-year plan was presented to the NSTX PAC for review and advice in January 2003. The input from the PAC was used in finalizing the NSTX 5-year plan.

The extensive interactions and discussions among the entire research team during this extended process of preparation have strengthened the effectiveness of NSTX national research collaboration.

Table 7.4. Previous NSTX Program Advisory Committee Members since FY 1997

Previous NSTX PAC Member	Institution
Prof. Gerald Navratil (chair)	Columbia University
Prof. Ray Fonck	University of Wisconsin
Prof. Ken Gentle	University of Texas at Austin
Dr. Dave Hill	Lawrence Livermore National Laboratory
Prof. Alan Hoffmann	University of Washington
Dr. Ed Lazarus	Oak Ridge National Laboratory
Prof. Farrokh Najmabadi	University of California, San Diego
Dr. Raffi Nazikian	Princeton Plasma Physics Laboratory
Dr. Robert Pinsker	General Atomics
Dr. Spencer Pitcher	Massachusetts Institute of Technology
Prof. Stewart Prager	University of Wisconsin
Dr. Steve Scott	Princeton Plasma Physics Laboratory
Dr. Ron Stambaugh	General Atomics
Dr. Alan Sykes	Culham Science Center (U.K.)
Prof. Yuichi Takase	University of Tokyo (Japan)
Dr. Stewart Zweben	Princeton Plasma Physics Laboratory

7.4 National Collaboration Research Capabilities and Plans

The NSTX 5-year plan has integrated the DOE-funded, planned contributions from the NSTX national collaboration team, which have durations ranging from 1-3 years. The Appendix provides a description of these collaboration research plans, plus additional exciting ideas that utilize the collaborators' expertise and extend the collaborative research contributions in important research topics to the 5-year horizon. These new ideas are generally consistent with the vision of the NSTX 5-year plan, as described in the preceding chapters. However, separate DOE reviews and approval will be required before these new plans could be finalized. The NSTX team will support these new proposals through the process of onsite Research Contacts and the Record of Discussion, and incorporate the funded collaboration activities into the NSTX national research plan in a timely manner.

The present review of the NSTX 5-year plan concentrates on the PPPL scope of work and the overall NSTX program and project plans. The Appendix summarizes the proposed scope of work by the collaborating groups during the 2004-2008 timeframe, as information helpful to the review of the entire NSTX program and project.

The research plans of the following collaboration team members are presented in the Appendix:

A-I. *Columbia University*
A-II. *Comp-X, Incorporated*
A-III. *General Atomics*
A-IV. *Johns Hopkins University*
A-V. *Los Alamos National Laboratory*
A-VI. *Lawrence Livermore National Laboratory*
A-VII. *Lodestar Research Corporation*
A-VIII. *Massachusetts Institute of Technology*
A-IX. *Nova Photonics, Incorporated*
A-X. *Oak Ridge National Laboratory – UT-Battelle*
A-XI. *University of California at Davis*
A-XII. *University of California at Irvine*
A-XIII. *University of California at Los Angeles*

A-XIV. University of California at San Diego

A-XV. University of Washington

A-XVI. University of Wisconsin-Madison

7.5 National and International Research Cooperation

Many fusion programs funded by DOE have participated in cooperative research and operations activities with the NSTX Team and will continue to in the future. These include substantive cooperation among the ST experiments in the U.S.: Pegasus at University of Wisconsin, HIT-II at University of Washington, and CDX-U at PPPL. The Pegasus experiment is designed to explore frontier ST physics of extremely strong toroidicity ($A \geq 1.1$), of HHFW and EBW heating and current drive in over-dense plasmas with very large dielectric constants ($\varepsilon = \omega_p^2/\omega_c^2 > 100$), and connections to the Spheromak, where the poloidal field can be much larger than the toroidal field. New results from Pegasus potentially will lead to future fundamental improvements in the ST and Spheromak configurations.

The innovative technique of Coaxial Helicity Injection (CHI) has been a key feature of the NSTX design, thanks to the close cooperation with the Helicity Injected Tokamak (HIT) research team since 1996. The HIT researchers have been members of the NSTX research team, and have led the CHI design, experimentation, and upgrades on NSTX. The close cooperation between HIT-II and NSTX has already led to major advances in the subject, including the solenoid-free startup of up to 400 kA in toroidal current via the CHI technique alone in plasma durations up to 300 ms, which are factors of 3 and 10 increases, in respective parameters, beyond the HIT-II results. Recent designs to improve the absorber (top) region insulator and poloidal field control were based on the successful experience on HIT-II and are being implemented on NSTX. A new operation scenario to reduce the helicity injection flux footprint in order to promote flux surface closure was recently suggested by the NSTX team, tested successfully on HIT-II, and will be tried on NSTX during the next campaign. CHI remains one of the key innovative techniques for solenoid-free operation that will continue to be tested and improved during the next 5 years.

CDX-U is one of the key components of the Virtual Laboratory for Technology (VLT) program to investigate the physics and technology of liquid (lithium)-surface plasma facing components. The NSTX and the CDX-U teams have cooperated closely to enable the planned tests of lithium coated walls during

FY04-05. These and additional tests on CDX-U aim to develop new database in support of a joint decision in FY06 with the Application of Liquid-plasma Interactions Science and Technology (ALIST) Working Group in the VLT ALPS program to design and build a lithium liquid surface module (LSM) and supporting systems for deployment on NSTX in FY08. Flowing lithium plasma facing surfaces hold the promise of substantial reduction of plasma recycling from the wall with potentially strong effects on confinement and indirectly stability properties of the plasma on NSTX. They could be further developed to handle sustained high plasma heat flux in future steady state fusion devices.

The NSTX research team has identified, jointly with the major tokamak research teams in the U.S. (DIII-D at GA and C-Mod at MIT), cooperative experiments to investigate size, aspect ratio, and β dependence in the confinement and stability properties of toroidal plasmas. NSTX researchers have encouraged and cooperated with innovative theory research activities (including the PPPL Theory Department) funded by the Theory Program of OFES to address new theoretical opportunities presented by the very high beta and strong toroidicity of the fusion-relevant plasmas enabled in ST experiments. NSTX further has provided attractive and well diagnosed laboratory plasmas, and the access interface needed, to reach new frontiers of fusion plasma measurements by a number of innovative development efforts that are funded by the Advanced Diagnostic Development Program of OFES and the SBIR of DOE.

A six-way cooperation in astrophysics and fusion plasma science is in progress involving scientists from the Chandra X-Ray Observatory Center, the OFES Advanced Diagnostic Development Program, KStar of Korea, LLNL, MIT, and NSTX in using the high-resolution X-ray crystal spectrometer, the first version of which was applied on PLT in 1985 for plasma temperature measurements. Of particular interest to astrophysics are the helium and neon-like ion spectra in the range from 5 – 20 Å to determine T_i based on density-sensitive line ratios. Helium-like argon spectra are routinely measured on NSTX for T_e and T_i. Scientists at LLNL and PPPL have a joint effort in improving modeling and interpretation of such spectra utilizing these measurements on NSTX. Recent comparison of T_e measured this way with T_e measured by laser Thomson scattering on NSTX has led to an improved benchmark of the theoretical models for these spectra in hot plasmas, which in turn can enable a more reliable determination of T_e of stellar plasmas. An NSTX X-ray imaging crystal spectrometer is currently also installed on C-Mod at MIT to provide core T_e and T_i measurements, which are very important to the confinement studies on C-Mod. An advanced 2D imaging spectrometer is currently developed under funding by the Advanced Diagnostic Program of OFES. A variant prototype of this detector being developed by KStar has been installed on

NSTX and is ready for testing in cooperation with the KStar diagnostic group. This diagnostic will provide important core T_i profile measurements on NSTX as a complement to the T_i measurements using the Charge Exchange Recombination Spectrometer (CHERS).

The NSTX research contributions have been further enhanced by a growing number of international collaborations with the world ST and toroidal experiments and researchers covering physics, diagnostic, and equipment. These include collaborations with researchers from the United Kingdom (MAST at the Culham Science Center), Japan (Hiroshima University, HIST at the Himeji Institute of Technology, Kyushu Tokai University, Niigata University, Tsukuba University, TST-2, TS-3, and TS-4 at the University of Tokyo, and JT-60U at JAERI), Russia (Globus-M at the Ioffe Institute, Kurchatov Institute-TRINITI), Korea (K-Star at the Korean Basic Science Institute, Korean Advanced Institute of Science and Technology), Brazil (ETE at the National Institute of Space Research, INPE), Italy (ENEA, Frascati), and France (CEA, Cadarache).

The research activities of the growing world ST community have benefited from the annual International ST Workshop since 1994. This workshop provides a special opportunity for the ST researchers to present the detail of their research results and plans for discussion and feedback, to develop new ideas of continued cooperation of mutual interest, and to provide helpful up-to-date information to new groups considering entering the ST research. ST experiments in the world at the concept exploration and proof of principle levels have recently grown to 14 in number.

More recently, NSTX has begun participating in all of the seven ITPA topical group activities upon recommendation by DOE and the ITPA, involving 12 members of the NSTX national research team (see, Chapter 6: NSTX and the Magnetic Fusion Energy Development Path). This represents an important way through which NSTX, together with MAST, plans to make substantial contributions to the international effort to enhance the ITER performance and improve the tokamak concept.

7.6 Enhancing and Expanding NSTX Collaboration

While the new NSTX national research team has already achieved a high level of national and international collaboration, the new and exciting NSTX research offers a wealth of opportunities for advancing the broad frontiers of fusion energy sciences. Compared to the collaborative research activities on major tokamaks in the U.S. and the world, the NSTX research effort is presently only in its fourth

year, and has great potential for enhancement and expansion. The following represent the major directions in this improvement for consideration by the NSTX national team, its management, and the fusion community

1) Strengthen coordination of research planning and implementation among all ST research programs in the U.S. (Pegasus, CDX-U, HIT-II, and NSTX), more effectively to explore the new ST limits of plasmas for further increases in plasma beta, confinement, and ease of sustained operations.

2) Broaden and strengthen the NSTX contributions to the ITPA, particularly on topics of comparison experiments of common interest with major tokamaks in the U.S. (C-Mod, DIII-D) and the world (JET, AUG, Tore-Supra, JT-60U). These experiments would aim to elucidate the physics effects of very low aspect ratio and very high beta on solenoid-less initiation and ramp-up of plasma current, stability, turbulence, rf heating and current drive, boundary physics, and integrated scenarios.

3) Begin a national Electron Bernstein Wave (EBW) physics and technology cooperative development program, jointly by the VLT and the ICC Programs. EBW, after conversion from Electron Cyclotron Wave (ECW), is a plasma wave that can propagate, heat, and drive currents efficiently and with precision in over-dense plasmas produced in ST, Spheromak, RFP, and FRC, etc. Experimental and theory/modeling investigations in the physics of EBW have very recently demonstrated a level of promise to warrant a major role on NSTX in achieving the research goals of the 5-year plan, which includes the development and deployment of 1-3 MW power. EBW experiments are also proposed on the MST RFP experiment. Whereas the frequency range of interest in today's experiments is likely to be only a fraction of 28 GHz, present technology is limited to power levels of up to 200 kW. It is therefore proposed that VLT develop efficient 1-MW sources as the most effective enabling technology to support the EBW research on these ICC experiments.

4) Identify additional research topics of common interest with other ICC experiments, such as Spheromak, RFP, FRC, and Compact Stellarators. These include the effects of lowered aspect ratio on turbulence, transport, and stability; the physics impact of varying magnetic fields so that $\square = \square_p^2/\square_c^2$ can range from 10^2 to 10^4; the consequences of very high local beta ranging from

order unity to greater than 10; etc. There is very high scientific incentive for cooperative investigations of these topics on these experiments.

5) Continue the pursuit to gain the EURATOM approval of the IEA Implementing Agreement (IA) on ST research cooperation in the world. An IEA IA on ST will provide an effective vehicle for coordinated ST research worldwide (including the formation of a comprehensive ST database), to enable the "internationalization" of the major ST experiments such as NSTX and MAST, to gain worldwide resources for ST research, and to contribute more effectively to the ITPA topical group activities.

These efforts combined, if successful, would increase the collaboration's fraction of a growing NSTX research team and increase productivity during the next 5 years. The expanded program proposed in the NSTX 5-year plan will create new opportunities for collaborators to expand their participation and new collaborators to join the Team.