PRINCETON PLASMA PHYSICS LABORATORY

A Department of Energy National Laboratory

Institutional Plan

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I. Laboratory Director's Statement

I.A. Overview

The goal of the United States Fusion Energy Sciences Program is to provide the knowledge base for fusion as an economically and environmentally attractive energy source. This document outlines the role of the Princeton Plasma Physics Laboratory (PPPL) helping to achieve this goal.

The last several years have been a time of considerable success at PPPL. A broader focus on approaches to innovation in fusion and a wider recognition of the impact of PPPL's efforts on other areas of science and technology have been hallmarks of this period.

PPPL's on-site and off-site near term activities support the achievement of the five year goals identified in the Integrated Program Planning Activity Report (DOE/SC-0028). We anticipate deeper understanding of transport and stability physics, based on theory, computation and detailed plasma diagnosis on a wide range of experiments. From NSTX we anticipate strong database on the attractiveness of the Spherical Torus concept, as well as improved understanding of general toroidal physics. While NCSX will be under construction at this time period, data from LHD will provide further insight into the capabilities of stellarators, particularly for stable long-pulse operation. We anticipate that there will be considerable understanding of feedback stabilization of instabilities in tokamaks, and of the possibilities for profile control, some of which will have already been applied to NSTX. We further anticipate that CDX-U will have provided key information on the use of lithium walls in MFE systems, with the possibility of practical application in NSTX.

I.B. PPPL Program

Innovative Confinement Configurations

A central element of the domestic Fusion Energy Sciences Program is "Innovative Confinement Configurations." PPPL has helped lead the national community in nurturing the best new ideas in plasma confinement both in advanced tokamaks and in innovative confinement configurations. The overall PPPL program is defined in the PPPL Program chart shown in Table 1. The key theme of the PPPL research program is to achieve innovation through deeper scientific understanding. Two major experimental projects, the National Spherical Torus Experiment (NSTX) and the National Compact Stellarator Experiment (NCSX) will anchor the Laboratory's concept improvement program for the next several years.

The spherical torus configuration is an innovative confinement configuration, which has the promise to combine stability at reduced applied magnetic field with good energy confinement. These properties flow from the combination of toroidal topology with an overall spherical shape. The role of the central core of the device is minimized without sacrificing its strong stabilizing influence. This advanced configuration may allow a relatively inexpensive fusion system to achieve high levels of fusion power in a compact size. The mission of NSTX, a national Proof-of-Principle spherical torus experiment, is to test this configuration at a scientifically relevant scale, but at minimum cost. By utilizing over $170M of PPPL site credits, a world-class, low cost device was constructed as a joint project of PPPL, Oak Ridge National Laboratory (ORNL), the University of Washington, and Columbia University. The NSTX Facility is being operated by PPPL as a national facility with collaborators from universities, industry, and National Laboratories. The NSTX first plasma was achieved ten weeks ahead of schedule on February 12, 1999. In FY02, a plasma current of 1.5 MA (50% over the design value) was achieved. A toroidal beta of 34% was achieved without active feedback control, substantially exceeding the FY02 goal of 25%. "H-confinement mode" plasmas were sustained for the preprogrammed durations of constant plasma current. Both plasma confinement and stability considerably exceeded predictions. In the light of this encouraging progress, options for upgrades to NSTX are being developed.

A successful outcome of the NSTX program would be to establish the foundation for an innovative national spherical torus experiment at the Performance Extension scale (see Table 1). An example of such an experiment could be a next step spherical torus (NSST) designed to achieve 5 - 10 MA in plasma current and, if performance projections are realized, to operate with deuterium-tritium fuel, thereby taking full advantage of the facility that will be available after the decommissioning and decontamination of the Tokamak Fusion Test Reactor (TFTR). Based on the encouraging high performance H-mode high-beta discharges on NSTX, it is envisioned that the NSTX may be able to supply the physics base needed for the physics validation of NSST by 2006. A timely start of NSST design and construction is needed to support an accelerated fusion energy development path which includes a Component Test Facility (CTF), as discussed in the 2002 Snowmass meeting.

The Laboratory's other major innovative confinement configuration initiative is the Compact Stellarator, which offers the attractive possibility of a disruption-free toroidal plasma that would operate in steady-state without external current drive, rotation drive or feedback systems. A proof-of-principle experiment based on the "quasi-axisymmetric" stellarator concept (QAS), the National Compact Stellarator Experiment (NCSX), is being designed by the Laboratory in partnership with the Oak Ridge National Laboratory, with the collaboration of many other institutions. The NCSX will be used to investigate the effects of three-dimensional plasma shaping, of internally- and externally-generated sources of rotational transform, and of quasi-axisymmetry on the stability and confinement of toroidal plasmas. Results from NCSX will be used to quantify the physics benefits of compact stellarators, passive stability and tokamak-like confinement including the ability to manipulate the turbulent transport with flows.

The NCSX project successfully completed a Department of Energy (DOE) peer review of its physics basis and physics design approach in 2001. The Fusion Energy Sciences Advisory Committee (FESAC) designated the NCSX as a proof-of-principle experiment, one which will examine a broad range of physics issues and provide the physics basis for assessing the concept's attractiveness for fusion energy and planning next steps. The FESAC said that the potential fusion gains "earn for the compact stellarator an important place in the portfolio of confinement concepts being pursued by the US Fusion Energy Sciences program." The DOE Office of Fusion Energy Sciences approved Critical Decision 0, Mission Need, authorizing the project to begin conceptual design. The Department requested $11M in its FY03 budget submission to Congress to initiate the $73.5M project. A successful DOE-SC "Lehman" conceptual design review of engineering, physics, cost and schedule took place on May 2002. Title I design is planned to begin in October 2002; equipment fabrication to begin in FY04; and operation to commence in June 2007.

The Laboratory has accepted a leadership role in nurturing the national innovative confinement configuration process and helps organize annual workshops to facilitate scientific dialogue and assessment of confinement concepts. PPPL is also performing theoretical analyses and developing proposals for experimental research in Field Reversed Configurations, within the Plasma Science and Technology Department, discussed below. We also actively support off-site concept-exploration experiments through PPPL's University Support Program.

Theory and Computation

With recent advances in computational power, capabilities to study all areas of plasma science have greatly expanded. PPPL has strong capabilities in linear and nonlinear simulations of transport phenomena, of macroscopic stability, and of the effects of energetic particles in plasmas. In addition to the goal of understanding plasmas, PPPL Theory and Computation contributes strongly to innovation in plasma confinement concepts, such as the spherical torus, the stellarator, feedback stabilization of tokamaks and stability of the Field Reversed Configuration. As a result, PPPL functions as a center for national and international collaboration in a broad range of areas of plasma science, which encompass fusion research and other areas of plasma scientific inquiry as diverse as space physics and the plasma thrusters. The PPPL Theory Department also plays a key role in the Princeton University Graduate Program in Plasma Physics.

In response to a request from the Office of Fusion Energy Sciences (OFES), PPPL has led a national effort to establish a Plasma Science Advanced Computing Institute (PSACI), which was stimulated by the need for to take advantage of advances in high-performance computer technology. In the process of developing a clear and compelling case for the inclusion of plasma sciences in proposed major programs such as the DOE Scientific Discovery through Advanced Computing (SciDAC) PPPL has assembled an outstanding Program Advisory Committee comprised of premier scientists from both within and outside of the plasma science community, and formed a multi-institutional management team. PPPL supports the SciDAC and is funded to do research in microscopic modeling of turbulent transport, macroscopic modeling of large-scale plasma instabilities and RF modeling. PPPL is also a partner in the SciDAC Fusion Collaboratory.

Off-Site Research

Members of the PPPL research staff are participating in experiments at leading national and international facilities, contributing important skills to the host teams, while strengthening the PPPL scientific program. National and international facilities provide opportunities for cutting-edge scientific research. While contributing to the programs at these facilities, PPPL scientists are taking advantage of resources at the Laboratory in the areas of theoretical support, diagnostic and radio frequency (RF) development, and integrative data analysis. This provides an excellent platform to address a wide range of key issues of fusion plasma science. Key interests of PPPL collaborators include advanced confinement regimes, magnetohydrodynamic (MHD) stability, RF physics, supra-thermal particle effects, and divertor physics.

In addition to scientific personnel, experienced engineers are contributing to the operations teams at DIII-D (located at General Atomics) and C-Mod (located at the Massachusetts Institute of Technology), and are helping with the design and construction of upgrades and modifications to these devices.

PPPL believes it is scientifically productive to maintain collaborative scientific teams. Even with a second proof-of-principle device on-site, such as NCSX, PPPL will still want to maintain a collaborative program at a very substantial level. In addition to the sharing of needed expertise, the scientific cross-fertilization that results from these collaborative programs is extremely important for the success of the Fusion Energy Science Program. For similar reasons, PPPL plans for strong incoming national collaboration on NSTX and NCSX.

Plasma Science and Technology

Small-scale experiments are undertaken at PPPL in the areas of basic plasma physics, innovative confinement configurations, and applied plasma technology. This research diversifies the Laboratory’s program, strengthens our connections with other fields of science, such as high energy physics and space physics, and plays an important role in the training of graduate students and postdoctoral associates. The Laboratory also encourages technology transfer from fusion research to meet the near-term practical needs of the nation, such as plasma processing technology, improved plasma thrusters for communications satellites, and advanced diagnostics for industrial processes.

TFTR Decontamination and Decommissioning

PPPL plans to complete the decontamination and decommissioning of TFTR by the end of FY02. This effort is currently ahead of schedule and under budget. The objective of this initiative is to bring a timely, cost-effective closure to the TFTR Project and to help demonstrate the safety and environmental attractiveness of fusion. The D&D process will allow the present TFTR Test Cell to be available for a future next-step “Performance Extension” device, such as NSST.

Burning Plasma Experiments

The 1998 FESAC Panel Report and the 1999 SEAB report supported the development of a burning plasma experiment. The fusion community, including PPPL, has been participating in the Next Step Options program to develop a concept for a minimum cost tokamak burning plasma experiment, called FIRE. We are also interested in the potential of the U.S. rejoining the ITER project as a junior partner. This will allow the US scientists an opportunity to study burning plasma physics in a large-scale, high-duty-factor device. If this occurs, an appropriate funding level will be necessary to be an effective partner in the ITER project. Indeed the PPPL perspective is that an effective fusion program requires both a strengthening of the domestic program of science and innovation, as well as collaboration in an international burning plasma experiment. As articulated by the various FESAC planning documents, it is only by the combination of understanding-driven innovation and a burning plasma experiment that it will be possible to provide humanity with cost-effective fusion systems. The Fusion Energy Sciences Advisory Committee (FESAC) is currently reviewing options for moving forward with a burning plasma experiment.

The Graduate Program in Plasma Physics and Science Education

The Laboratory places great importance on the continuation of its close relationship with the Princeton University Program in Plasma Physics. The Program, with over 200 Ph.D. graduates since its inception, provides training in plasma physics relevant to magnetic fusion, as well as in the broader field of plasma science. The scientific diversity of PPPL, as well as its outstanding capabilities in magnetic-confinement fusion, continues to attract the highest quality students to the Program. Within the School of Engineering, the Program in Plasma Science and Technology brings together students from a broad range of departments involved in plasma studies, building ties to fusion plasma science.

The Science Education program serves undergraduates and students and teachers in grades K-12. Programs include scientific research experiences, partnerships with school districts, teacher staff development, and curriculum development with an emphasis on Internet-based science investigations for students.

University Relations

Princeton University is the contractor for the Department of Energy. As such, the Laboratory places great importance on the continuous strengthening of its close relationship with the Princeton University. The Laboratory as well as the University benefit from the collaborative relations that occur in a number of Departments and Programs – Astrophysical Sciences, Computer Science, Mechanical and Aerospace Engineering, Applied Mathematics, the Princeton Materials Institute, the Center for Energy and Environmental Studies. By synergistically utilizing these resources both organizations benefit from the exchange of ideas, resources and personnel.

I.C. Organization

Table 2 shows the Laboratory organization. Projects are arrayed on the left-hand side of the chart, while the supporting functions are aligned on the right-hand side. This organizational structure is working well, with the support organizations successfully supplying capabilities to the projects, large and small, on-site and off-site, in an effective manner. The "ladder" of Science Focus Groups has also been successful in providing ongoing scientific focus and coordination to the PPPL activities that cover a wide range of scientific endeavors. In general PPPL management has been able to avoid the sort of "silo" mentality that can develop in organizations, and indeed there is a strong sense in the leadership that the whole Laboratory (and indeed the whole Fusion Energy Sciences program) succeeds or fails together.

I.D. Conclusions

PPPL has a bright future, because the Laboratory's strengths and strategic plan are aligned to the goals of the US Fusion Energy Sciences Program. The success of PPPL is a key factor in the success of the overall Fusion Energy Sciences Program. Success in achieving a positive future for the Laboratory and the Program will require a continuing cooperative spirit among PPPL, OFES, and the national fusion research community.

II. Laboratory Mission, Vision and Core Competencies

II.A. Mission/ Vision

The PPPL Mission

The DOE Princeton Plasma Physics Laboratory is a Collaborative National Center for plasma and fusion science. Its primary mission is to develop the scientific understanding and the key innovations which will lead to an attractive new energy source. Associated missions include conducting world-class research along the broad frontier of plasma science and technology, and providing the highest quality of scientific education.

The PPPL Collaborative Vision

Deepening the understanding of plasmas and creating key innovations to make fusion power a practical reality.

II.B. PPPL Role in DOE Laboratory System

PPPL is the only single-purpose Laboratory funded by the US Department of Energy for the development of fusion and for research in the underlying discipline of plasma science. PPPL teams with other National Laboratories to achieve the DOE's goals. A particularly strong example of this is the PPPL/ORNL collaboration on the Compact Stellarator design.

II.C. Core Competencies

The Laboratory has a highly skilled work force and extensive capabilities for the experimental and theoretical study of fusion and non-fusion plasmas and for the integrated design, fabrication, and operation of experimental plasma facilities of all types. Management by Princeton University provides the institutional framework for a broad laboratory-based program of education in plasma physics and related science and technology. Core competencies of PPPL are:

Plasma Science and Technology

- Experimental analysis of stability and confinement in fusion plasmas.
- Plasma theory for fusion and other applications.
- Computational physics and numerical simulation of plasma processes.
- Physics design of experimental plasma facilities.
- Physics and technology of plasma heating and current-drive, including neutral beam and radio-frequency techniques.
- Physics and technology of plasma diagnostics and instrumentation.
- Physics and technology of plasma applications to advance industrial technologies.
- Design and implementation of basic plasma physics experiments, such as used for studies of magnetic reconnection or plasma-surface interactions.

Engineering

- Engineering design and analysis of experimental plasma facilities including magnetics, neutronics, thermal, and structural analysis.
- Systems integration and construction management for experimental plasma facilities.
- Operation of experimental plasma facilities.
- Mechanical engineering, including structures, vacuum, cryogenic, and tritium systems.
- Computer engineering, including data-acquisition, instrumentation, and controls systems.
- Electrical/electronic/electro-optic engineering, including power conversion, diagnostic, and radio-frequency systems.
- Environmental, safety, and health aspects of the operation and decommissioning of contaminated and activated experimental fusion devices, including tritium operations.

Education

- Provision of faculty for an integrated program of courses and research supervision for graduate students in plasma physics and related science and technologies.
- Implementation of a broad science education program for the community-at-large, including undergraduate and pre-college students and science and mathematics teachers at all levels.

III. Laboratory Scientific and Technical Vision and Strategic Plan

The January 27, 1996, report of the Fusion Energy Advisory Committee, titled “A Restructured Fusion Energy Sciences Program,” resulted in the goals for the national fusion energy program. The fusion mission states:

Advance plasma science, fusion science, and fusion technology — the knowledge base needed for an economically and environmentally attractive fusion energy source.

The Department of Energy policy goals to assist in achieving this mission are:

Advance plasma science in pursuit of national science and technology goals.

Develop fusion science, technology, and plasma confinement innovations as the central theme of the domestic program.

Pursue burning plasmas and fusion energy science and technology as a partner in the international effort.

III.A. Vision and Strategic Goals

The national fusion mission and goals are deeply consonant with the mission and core competencies of the Laboratory, including the educational goals of the Laboratory and Princeton University. The current challenge to the Laboratory is to find the most cost-effective methods possible to help the DOE achieve these national goals.

The programs and activities listed below constitute the strategic approach PPPL has chosen to contribute to meeting the national goal for the Fusion Energy Sciences Program. The program is also shown in Table 1, PPPL Program Plan. The associated funding, organization, staffing, and resources by program are shown in Tables 2, 3, 4, 5 and 6. The PPPL Program includes: National Spherical Torus Experiment; Off-Site Research; Advanced Projects; Plasma Science and Technology; Theory and Computation; Laboratory Program Development Activities; Education; TFTR D&D and Caretaking.

In examining Tables 2-6, and in reading the following text, it is important to recognize that the program described here is envisioned to encompass a wide range of important scientific opportunities. It is recognized that some of the scientific initiatives described here may not be implemented, due to limitations in DOE funding and the need to maintain an institutionally balanced program retaining national core competencies.

III.B. Critical Success Factors

There are several critical success factors, which must serve as institution guides in order that PPPL meet its mission and the strategic goals. These include:

- Perform work safely and with high environmental responsibility.
- Meet and exceed commitments made to our customer (DOE).
- Strengthen and broaden collaboration both within the fusion community and in the wider science and technology communities
- Innovate on the basis of solid scientific understanding in order to advance fusion and plasma science.

III.C. National Spherical Torus Experiment

PPPL is responsible for the operation and management of the NSTX facility. The NSTX research is being carried out by the National Research Team to prove the physics principles of very low aspect ratio spherical torus (ST) plasmas. The ST has emerged as an attractive confinement concept and promises many desirable plasma properties that are of high scientific interest and may help reduce the cost of developing fusion energy applications in the future.

NSTX will carry out this investigation in plasma discharges with significant pulse lengths (up to 5 seconds) using an array of plasma heating, control, and diagnostic techniques. The Project installed a Neutral Beam Injection (NBI) system with 5 MW, 5-second capability in FY00.

The objective of the NSTX Research Program is to examine: 1) the physics principles of plasma startup in an ST without relying on an inboard solenoid magnet; 2) effective heating and non-inductive current drive for steady-state operation; 3) stably confining high plasma pressure at low magnetic field; 4) the possibilities for maintaining high fractions of self-driven (bootstrap) plasma current; 5) achieving good energy confinement in a small-size plasma; and 6) dispersing heat and particle fluxes at the plasma edge. Positive outcomes of these investigations would lead to ST fusion devices combining high fusion performance, small size, feasible power handling, and good economy.

The present NSTX Research Program began in FY00, and is planned to carry out research for a 10-year duration in three phases emphasizing successively Inductive, Noninductive Assisted, and Noninductive Sustained plasma operations. The Inductive operation phase successfully concluded during FY00. It involved commissioning of initial plasma operations and diagnostics, and experiments to optimize plasma startup and confinement primarily with resistive heating.

The Noninductive Assisted operation phase began in FY01, and is expected to require 4 years. This phase aims to investigate ST plasmas characterized by average toroidal betas up to 25%, significant bootstrap current fraction ~ 40%, and confinement above the tokamak "Low-confinement mode" scaling expressions. Active feedback stabilization of MHD modes is not anticipated to be necessary during this operation. Already, in June 2002, a toroidal beta of 34% has been reached and plasmas in the tokamak "High-confinement mode" have achieved confinement times above the standard tokamak scalings for both low and high confinement modes.

The Noninductive Sustained operation phase is expected to begin in FY05 for a four-year period. Experiments will investigate ST plasmas with elongations up to 2.5 with average toroidal betas up to 40%, bootstrap current fraction up to ~70% well aligned with the total current profile, and excellent energy confinement. Control of MHD modes in the presence of a stabilizing resistive wall and all plasma profiles are anticipated to be necessary to approach this “wall-stabilized” regime. The Noninductive Assisted Phase Experiments on NSTX should provide important initial data on the resistive wall modes to determine requirements for active feedback stabilization. Additional data for active feedback stabilization should become available from the on-going tokamak experiments (e.g., DIII-D, and HBT-EP) to enable design of an active feedback control system on NSTX for resistive wall modes. PPPL is a major collaborator in the DIII-D resistive wall mode experiments. The phase-I feedback stabilization tools will be designed in FY03 and implemented in FY04 to enable the Noninductive Sustained Phase experiments.

The NSTX research program is expected to contribute much to the understanding of fusion-relevant ST plasmas of very high beta, high temperature and low collisionality in particular, toroidal fusion plasmas in general, and naturally occurring plasma phenomena in space. The considerations include:

- Noninductive plasma formation via Coaxial Helicity Injection and Electron Bernstein Wave (EBW) Heating and Current Drive, taking advantage of the small magnetic flux content in the ST plasma. The physics mechanisms of non-inductive startup in ST (field line reconnection and large plasma flow) have been observed in the HIT (Helicity Injected Tokamak) and the HIT-II experiments at the University of Washington, and are similar in nature to the physics responsible for the formation of solar flares.

- Heating and current drive via High Harmonic Fast Wave (HHFW), EBW, and Neutral Beam Injection (NBI), taking into account the strong local magnetic shear, very high dielectric constant, supra-Alfvén energetic and tail thermal ions and the small magnetic flux of the ST plasma. This parameter regime also characterizes much of the ionospheric and stellar plasmas, and their interactions with electromagnetic waves and energetic particles.

- Very high stability and operation limits, taking advantage of naturally large stable elongations, strongly stabilizing magnetic field line structure, modest Alfvén speed compared to sound speed, minimal external plasma inductance, the potential for large fully aligned bootstrap current, and inboard rigidity of poloidal flux (increasing resilience to plasma disruptions). Local plasma beta (ratio of plasma pressure to magnetic field pressure) values of order unity are anticipated in the ST, which far extends the present database of modest beta for high temperature collisionless toroidal plasmas. As the aspect ratio approaches the lower limit of unity, the spherical torus also approaches the physics regimes of Field Reversed Configuration (FRC) and Spheromak, likely extending their existing database from modest temperatures to high-temperature collisionless plasmas.

- Reduced microturbulence and enhanced transport barriers, taking advantage of the reversal of particle precession at high beta, the very large sheared flow at high beta and momentum input, large gradients in beta, larger ratios of ion gyroradius to plasma size, and compressed neoclassical orbits due to the large pressure gradients and plasma flows. Such plasmas are likely to reveal an increased role for small size scale electromagnetic turbulence relative to the electrostatic turbulence that has so far dominated the low-beta toroidal plasmas. New understanding of electromagnetic turbulence in the ST will also contribute directly to the progress of research in FRC, Spheromak, and even plasmas in astrophysical accretion disks

- Edge and Scrape Off Layer (SOL), divertor and limiter, taking advantage of the large magnetic mirror ratio, outboard field line curvature, and flux-tube expansion in the outboard SOL. Such a SOL configuration represents a "strongly twisted magnetic mirror" and offers a direct link in plasma physics between the toroidal and linear magnetic confinement devices.

- Integrated and sustained operation, taking advantage of the above ST plasma features and the high edge safety factor in the presence of hollow current profiles – but monotonic q profiles. New prospects for beneficial synergy among these physics features in the advance physics regime are introduced by the ST: very high stable beta with hollow current profiles, strong suppression of turbulence, improved neoclassical transport, large and aligned bootstrap current, and reduced major radius that eases non-inductive current drive. Success in these physics developments would establish a new and attractive scientific basis for fusion energy and its development.

A collaborative national team was formed in 1999 to carry out the NSTX Research Program. A management approach has been developed with DOE to implement and strengthen the national research program. Desirable upgrades are being incorporated into the NSTX National Research Plan. A strong NSTX Program Advisory Committee, composed of senior US and world fusion researchers meeting two times a year, has been active since July 1996 in shaping the very successful NSTX Project and Program.

In order to support the exciting scientific research program on NSTX, a number of sophisticated profile diagnostic upgrades are being proposed by both PPPL and collaborating institutions. Major proposed diagnostic enhancements include MSE/LIF to measure the plasma radial electric fields as well as the plasma current profiles, low-k imaging and high-k microwave scattering systems to characterize the plasma turbulences responsible for the plasma and energy transport, and poloidal CHERS to measure the plasma poloidal flows to complement the existing toroidal CHERS system.

An exciting near term facility upgrade possibility on NSTX is the incorporation of advanced plasma facing components using liquid walls, such as lithium. Liquid lithium could improve plasma performance by reducing plasma edge recycling while protecting the solid wall from intense heat and particle flux expected in high performance ST plasmas. With a proper flow control, the moving liquid lithium can also be used to stabilize the MHD modes, acting as a moving stabilizing wall. The liquid lithium experiment on CDX-U and other devices, and the lithium module development and test by the National Virtual Laboratory of Technology should provide sufficient data for a decision point in FY03-04 with implementation on NSTX in the FY05-06 time frame.

A further potential upgrade to the NSTX facility is an Electron Bernstein Wave (EBW) heating and current drive system. Theoretical studies indicate that EB waves may be very efficient for current drive, due to their electrostatic nature near resonance, and that such waves may be practical to launch in highly over dense plasmas such as NSTX. Experimental studies of EBW emission from CDX-U and NSTX are encouraging that antennas can be designed to launch electromagnetic waves which couple into EB waves in a steep density gradient region with high efficiency. An EBW heating and current drive system could provide surgical accuracy for stabilization of neoclassical tearing modes, as well as high efficiency for current drive, at a small fraction of the cost of the high-frequency systems required for EC heating and current drive in conventional tokamaks. An important decision point for the phase I EBW system is expected at the end of FY 03.

After completing the next five-year research plan on NSTX, an upgrade of the center stack can be envisioned. The new center stack will enable the NSTX to perform at significantly higher plasma current for a long pulse operation. The higher operating current will enable NBI to operate at higher efficiency and the longer pulse capability will enable NSTX to make further progress on the FESAC 5 - 10 year goal of ST attractiveness assessment for τ-pulse >> τ -skin. NSTX, with an upgraded center stack, can continue spherical torus research, in support of NSST operations, during the NSST construction phase.

III.D. Off-Site Research

PPPL's Off-Site Research program is targeted at the performance of forefront research on key scientific questions using leading facilities in the US and abroad. The motivation for PPPL's off-site collaboration program is that certain key issues in fusion energy science are both important for US research and require the use of off-site facilities. Domestic off-site tokamak facilities afford opportunities for innovations and for studies of knowledge-based plasma control at medium size-scale. International tokamak facilities, which lead in size-scale (which is the dimension that demands the greatest extension in making projections to reactor-scale facilities), afford opportunities for studying the size-scaling of key issues such as transport barriers, core/edge balance, neoclassical tearing modes, resistive wall modes, and energetic particle modes. International stellarator facilities allow PPPL researchers to explore a confinement configuration that is more externally controlled, operates in steady state without current or rotation drive, and which may offer a path to avoidance of disruption-related problems in tokamaks. In this case, and in the case of tokamak research, strong linkages between off-site activities and on-site research help to strengthen scientific collaboration both nationally and internationally, and assure that the latest understanding and techniques travel quickly from team to team.

Working with the US community and the leaders of the programs at Alcator C-Mod (at MIT, Cambridge, Massachusetts), DIII-D (at General Atomics, La Jolla, California), JET (in Abingdon, England, under the European Fusion Development Agreement EFDA), JT-60U (in Naka, Japan), and LHD (in Toki, Japan), scopes of work that address key issues in fusion research have been defined for PPPL research-participation. These issues include optimization of the tokamak concept by measurement and control of the profiles of the plasma current density, plasma pressure, and transport as well as improvement of plasma stability by feedback control of resistive wall modes and neoclassical tearing modes. On LHD, the issues include exploration and advancement of the stellarator concept and application of diagnostic and analysis techniques to increase understanding. PPPL focuses its off-site research on specific high-priority goals, fielding research teams that function as members of research programs at remote facilities, but with strong intellectual ties to the Laboratory. PPPL recognizes that participation in off-site research is best achieved via strong partnership in remote programs as integrated members of the remote program's research team. Table 8 provides statistics on the collaboration effort at the various research facilities.

In addition to scientific personnel, experienced engineers and highly skilled technicians contribute to the operations team at DIII-D and C-Mod, and help design and construct upgrades and modifications to these devices.

The scopes of off-site research programs are summarized in the following paragraphs.

- On DIII-D, the programmatic foci are in the areas of MHD stability generally and feedback stabilization of MHD modes specifically, transport, and RF heating and current drive. In MHD, PPPL researchers and engineers have designed and installed feedback stabilization tools (including saddle coils for signal detection and feedback power supplies for nonaxisymmetric coils), have designed, fabricated, and utilized steerable electron cyclotron current drive launchers for current profile control and feedback stabilization of neoclassical tearing modes, and are developing and applying data analysis codes, coupling PPPL theory codes to DIII-D data, and developing enhanced MHD and disruption diagnostics. In transport, PPPL researchers are analyzing experimental data, participating in transient heat pulse and transport barrier experiments, and participating in the development of advanced diagnostics. In RF heating and current drive, the steerable electron cyclotron current drive launchers are used for studies of the fundamental physics of wave propagation and absorption.

- On C-Mod, the programmatic foci are RF heating and current drive, advanced tokamak research, and transport. PPPL has augmented the C-Mod Ion Cyclotron Range of Frequencies (ICRF) system capability with two RF transmitters and a 4-strap RF antenna and installed several diagnostics that support the research program. The Motional Stark Effect (MSE) will provide key information on the profile of the plasma current; its operation is expected to start as soon as the Russian-built diagnostic neutral beam is injected into plasma. PPPL is also working with MIT on the design, installation, and operation of a lower-hybrid current-drive system on C-Mod for off-axis current drive; PPPL has a long history of involvement in lower-hybrid research, most recently on the PBX-M experiment; MIT was a collaborator on the PBX-M lower hybrid experiments, particularly in the study of energetic electron generation and transport. The lower hybrid system will contribute to advanced tokamak research by permitting studies of the effects of plasma current profile on the stability and transport of the C-Mod plasma for times longer than the current redistribution time. In transport, PPPL has installed and utilized a gas-puff imaging diagnostic that views the light emitted as a burst of gas is injected into the plasma; it has shown intriguing structures for the turbulence in the plasma edge. PPPL also performs transport simulations and benchmarks transport theories against the C-Mod data.

- On JET, the near-term areas of concentration are transport and stability studies, especially for plasmas with reversed shear. A key medium-term area is burning plasma physics, exemplified by participation in their deuterium-tritium programs. PPPL is engaged in studies of "optimized shear plasmas," both by design, fabrication, and operation of a MSE system (collaborating with Culham Laboratory) and by participating in analyses and experiments targeted at plasma performance enhancement. In addition, an on-site PPPL researcher is playing a key role in both plasma operations and a collaborative study of the plasma edge. PPPL is installing a reflectometer system for measuring the characteristics of the plasma turbulence in JET. PPPL researchers are also engaged in planning diagnostic and plasma control systems for the JET Extended Performance phase. PPPL has proposed that the US be more strongly involved in the future in JET.

- On JT-60U, three areas of study have been conducted: high-beta plasma research, including transport analysis of reversed-shear plasmas, instabilities driven by the high-energy ions from their high-energy neutral beam (burning-plasma physics), and MHD activity and disruptions.

- PPPL has designed diagnostic cassettes for the KSTAR superconducting advanced tokamak program in South Korea. PPPL is very interested in working with the Korean and international teams to increase the capability and flexibility of KSTAR and to exploit its capabilities for increasing the understanding of long-pulse tokamak plasmas.

In the innovative confinement configurations arena, the Laboratory's on-site activities in stellarator physics are being complemented by increasing collaboration on international stellarator programs in Japan and Germany, and its on-site spherical torus research will be augmented by collaboration on MAST (located in England). On LHD in Japan, PPPL is studying fast-ion loss, magnetics diagnostics, beam particle loss using a TFTR neutral particle analyzer, and electron cyclotron emission. On Wendelstein in Germany, PPPL will analyze the stability of current-carrying plasmas.

III.E. Advanced Projects

The Advanced Projects Department is responsible for the stellarator initiative discussed in Section IV.A, Next Step Options, and Fusion Technology .

Next Step Options

As a result of recommendations by the 1998 Grunder FESAC Panel Report and the 1999 SEAB Report on Realizing the Promise of Fusion Energy, a US Next Step Option design activity has been organized to develop a concept for a burning plasma experiment that would allow the exploration of the relevant science at lower cost than ITER. In keeping with the potential roles for significant initiatives in the fusion program, primary consideration is first being given to an experiment that focuses on tokamak burning plasma physics. The programmatic objective for this study is to identify and characterize a burning plasma experiment facility suitable for a constrained funding environment.

The Next Step Option studies are part of the Virtual Laboratory for Technology and organized as a national activity involving many US fusion laboratories, universities and industry. PPPL has been assigned several leadership roles. These include both project head and physics head for the burning plasma option being assessed.

A pre-conceptual design is being developed for a high field, copper magnet burning plasma experiment, Fusion Ignition Research Experiment (FIRE). Its mission would be to attain, explore, understand and optimize fusion-dominated plasmas to provide the knowledge needed for the design of attractive MFE systems. The configuration features liquid nitrogen cooled magnets, a toroidal field of about 10T, fusion power levels of 150 - 200 MW, burn times of ~ 20 s. The high field magnet will accommodate longer pulse lengths at moderate fields to contribute to the long pulse advanced tokamak objective. After supporting the Snowmass process in FY02 the next step in design progression of this option may be the completion of pre-conceptual technical design and cost estimates of the baseline configuration, identification of critical physics and engineering R&D activities and evaluation of opportunities to optimize the design point. A NSO Program Advisory Committee has been formed to guide NSO activities.

The potential role of the United States in the international ITER project is under serious discussion. If a significant role for the U.S. is established, PPPL, as the only single-program national laboratory for fusion, should be a major contributor to the management and science of this endeavor. Key areas where PPPL can contribute in management include nationally-based technical coordination such as was established for TPX, and which has contributed to the success of NSTX. In this context PPPL is well-positioned to organize the awarding of industrial contracts using top-notch technical management talent, and without perceived or actual conflict of interest. From a scientific point of view, PPPL is also uniquely well positioned to contribute to the design and manufacture, for example, of neutron-hardened plasma diagnostic systems.

Fusion Technology

It is important that PPPL play a significant role in fusion technology development. Areas where technology development activities are carried out within the Advanced Projects Department are as follows:

Power Plant Studies: PPPL has participated in the national Power Plant studies, ARIES, for 12 years, for example taking a leadership role in developing the "advanced tokamak" concept incorporated in the ARIES-RS and ARIES-AT designs. Present participation is both in the physics design effort and the engineering design and analysis. In FY01 the ARIES studies focused on a new initiative to scope options for IFE reactors. In FY03 a compact stellarator reactor study will be initiated that will continue for several years. Beyond this time frame, PPPL advocates further work on the fusion development path, including non-tokamak alternatives.

Advanced Power Extraction Studies: A criticism of present magnetic fusion reactor conceptual designs is that the materials and configurations for the first-wall, blanket, and divertor restrict reactor operation. There is a national effort to develop and assess alternative concepts for the first wall, blanket, and divertor, which are capable of high-power density operation and permit enhanced component lifetimes. This is a joint effort involving the Advanced Power Extraction (APEX) and Advanced Liquid Plasma-facing Surface (ALPS) fusion technology programs. The PPPL Advanced Projects Department contribution is divided between physics integration and engineering of liquid first walls. (See below for contributions by CDX-U within the Plasma Science and Technology Department.)

Diagnostic Technology Development Progress in fusion research relies heavily on detailed measurements of plasma parameters. In recent years, for example, continuing improvement in profile diagnostics coupled with the emergence of increasingly sophisticated turbulence diagnostics has begun to provide physicists with the depth of data needed to test the understanding of plasma transport being developed through the use of advanced parallel computers PPPL has an experienced team of physicists and engineers actively pursuing many new diagnostic directions, for use both on PPPL devices and on other fusion devices around the world. PPPL is also actively collaborating with several universities and industries to develop innovative diagnostic instrumentation. In addition, PPPL researchers are active in planning aimed at meeting the challenges of diagnosing a burning plasma experiment.

RF Technology. The objective of the PPPL RF technology development is to provide RF antenna, matching and source systems which will serve to realize the full potential of RF techniques for application to reactor regime plasmas and for supporting the development of both the advanced tokamak and innovative confinement configuration paths to potential reactor devices. This work is a central element of PPPL's off-site research engagements, with ICRF antenna systems being provided for C-MOD and JET, a LH launcher being constructed for C-MOD, and ECH/ECCD antennas being provided for DIII-D and KSTAR.

Socio-economic Studies. Fusion is not being adequately factored into long-term energy planning even though the need for long-term non-carbon-dioxide producing energy options has been clearly identified. PPPL is developing fusion implementation scenarios that demonstrate the potential role of fusion during the second half of the 21st century, and is working collaboratively to have these ideas incorporated in scenarios develop ed by the energy and environment community.

III.F. Plasma Science and Technology

The Plasma Science and Technology Department supports the Laboratory mission by performing basic research to acquire new knowledge in plasma science, and by using this knowledge to develop new plasma technologies, both in and outside of fusion research. While constituting only a small percentage of the Laboratory's funded activity, this Department plays a critical role in providing scientific breadth and diversity. The department also plays a major role in the training of graduate students and postdoctoral associates. These missions are accomplished by:

- Performing versatile, science-focused experiments on basic plasma physics and innovative confinement configurations at PPPL and at other universities and research sites.
- Applying plasma theory to other disciplines, such as high current high-energy accelerators and industrial applications.
- Developing near-term applications of plasma science which demonstrate the practical value of the research performed at the Laboratory to meet both commercial and government needs.
- Providing experimental facilities and physics expertise for Princeton University graduate student Ph.D. theses and for work by PPPL postdoctoral students.

The present direction of the Plasma Science and Technology Department is to strengthen its existing programs on:

The Current Drive Experiment - Upgrade (CDX-U): The CDX-U facility is now employed to test the use of liquid metals, in particular liquid lithium, as plasma-facing components. A liquid first wall offers many advantages over solid plasma-facing components in a reactor, if it can be successfully implemented. Lithium walls may also provide access to novel plasma regimes. As part of the Advanced Liquid Plasma-facing Surface (ALPS) Program in fusion technology, CDX-U has successfully tested a large area fully toroidal liquid lithium limiter as a plasma-facing component. The performance of the limiter was acceptable from an engineering standpoint, and furthermore produced an enhancement of plasma performance. The next experimental phase will involve installation of a circulating liquid lithium limiter system as a test of a more ambitious implementation of liquid lithium as a limiter or divertor target, now proposed for NSTX. It is also proposed to extend experiments on novel plasma regimes accessible with non-recycling walls to a new experiment – the Lithium Tokamak eXperiment or LTX.

The Magnetic Reconnection Experiment (MRX): devices such as MRX are test beds to develop innovative ideas and test basic understanding of plasma physics. The MRX facility is jointly funded by the DOE, the National Aeronautics and Space Administration (NASA), and the National Science Foundation (NSF). Research focuses on magnetic reconnection, which is one of the most fundamental plasma physics issues in both laboratory and space plasmas. MRX data has already made a significant impact on space and astrophysics by providing clues for understanding collisionless reconnection, merging angle dependence and the validity of Sweet-Parker reconnection models. The present research is focused on non-MHD physics in the reconnection layer. Future study will cover plasma acceleration, 3-D reconnection, global MHD effects and magnetic helicity evolution during reconnection. Research on the formation of FRC and possible low-aspect ratio toroidal plasmas in MRX, through magnetic reconnection, may also provide the scientific basis for the future innovative experimental studies.

Recently a multi-institutional proposal, led by the University of Wisconsin, for a "Physics Frontier Center" has been approved by the National Science Foundation. The MRX experiment is an integral part of this proposal, and will be funded by OFES for significant upgrades as part of that activity. The Center arrangement is planned to lead to enhanced interactions amongst laboratory experimentalists, theorists from both the fusion and astrophysics communities, and observational astrophysicists.

Theory and experiments on nonneutral plasmas are aimed both at basic plasma physics and at new applications, ranging from high-energy particle accelerators to the development of a new type of vacuum pressure sensor. Experimental and theoretical research is carried out to investigate the basic properties of nonneutral electron plasmas confined in a Malmberg-Penning trap, and the interaction of the plasma electrons with background neutral gas. Advanced analytical and numerical studies are also carried out to investigate the nonlinear beam dynamics and transport properties of intense nonneutral beams propagating in periodic-focusing accelerators and transport systems, with particular emphasis on next-generation accelerators for heavy ion fusion, spallation neutron sources, and high energy physics applications.

Heavy Ion Fusion Virtual National Laboratory: The Princeton Plasma Physics Laboratory, together with Lawrence Berkeley National Laboratory and Lawrence Livermore National Laboratory, are vital participants in the Heavy Ion Fusion Virtual National Laboratory. The long-term objective of the U. S. heavy ion fusion program is to provide a comprehensive scientific knowledge base and the enabling technologies required for inertial fusion energy driven by high-brightness heavy ion beams. A fundamental theoretical and experimental understanding of nonlinear space-charge effects on the propagation, acceleration and compression of high-brightness (high-current and low-emittance) heavy ion beams is essential to the identification of optimal operating regimes in which emittance growth and beam losses are minimized in periodic focusing accelerators and transport systems for heavy ion fusion. Building on PPPL's considerable technical expertise, the Laboratory's participation in Virtual National Laboratory research activities focuses on: (a) development of advanced analytical and numerical models describing the nonlinear dynamics and collective processes characteristic of intense heavy ion beam propagation in periodic focusing accelerators and transport systems, including the identification and mitigation of the effects of collective beam-plasma interactions in the target chamber; (b) experimental investigations of the effects of multielectron loss events on heavy ion beam propagation in the target chamber; (c) development of novel rf source techniques for preionized plasma formation to be implemented at LBNL on the Neutralized Transport Experiment to study collective beam-plasma interactions; and (d) the development of engineering design capabilities describing pulse compression scenarios, the final focus magnet system, and the vacuum pumping system at the target chamber interface.

The Magnetic Nozzle Experiment (MNX) investigates collisional recombination promoted by interactions with neutral gas. This is a small-scale experiment on magnetized plasmas, concentrating on atomic physics and plasma physics and their applications to space propulsion, materials processing, and compact aneutronic fusion experiments. These studies build on collaborations with FRC experiments at the University of Washington. The same device will be used for the new FRC/RMF experiments (see below).

Plasma applications include the development of a new technique for food sterilization using RF and microwaves, plasma applications related to spacecraft thrusters, and applications related to improving plasma display panels. PPPL has also initiated a new plasma application to improve plasma sterilization techniques that would potentially have application in the food and beverage industry.

Off-site university research support which offers the scientific and technological resources of PPPL to university programs in fusion science, particularly to those smaller plasma groups which could most benefit from "scientific outreach" by PPPL. This program allows PPPL scientists and engineers to collaborate with Universities in such areas as: experimental device design, diagnostics, data acquisition and analysis, plasma heating systems, engineering, and theory. All types of OFES-funded University research are supported, including innovative confinement configurations in both MFE and IFE, and basic and applied plasma science. It is expected that each of these support programs will complete its initial goals after about 3 years.

FRC/RMF experiment: an experimental study of particle heating by rotating magnetic fields (RMF) in FRCs having closed flux surfaces. The experiments will examine solutions to a long-standing fundamental problem in Field-Reversed Configuration (FRC) physics: how to apply rotating magnetic fields that maintain a closed field-line structure. Based on recent advances in the theoretical understanding of FRC physics, the novel fields to be used in this experiment are predicted to heat electrons and ions, to drive current, and to provide improved stability. RMFs have been successfully used, particularly in rotomak devices. The standard (i.e., even-parity) RMF configuration, however, is predicted to open the FRC's field-line structure. Larger, higher power RMF experiments are in progress. They aim to produce higher temperature plasmas, more susceptible to open-field-line particle and energy losses. This possibility strongly motivates the studies of field-closure-conserving RMF configurations and their effects on particle confinement and heating. A small experimental facility will compare operation with both even-parity and odd-parity RMFs at high power densities. Combined with a low neutral pressure and relatively remote (10 cm) walls, detrimental plasma-wall interactions and atomic physics effects would be minimized.

Paul Trap Experiment: has been initiated to simulate intense nonneutral beam propagation through a periodic focusing quadrupole field configuration. Periodic focusing accelerators and beam transport systems have a wide range of applications ranging from basic scientific research in high energy and nuclear physics, to applications such as nuclear waste transmutation and heavy ion fusion. The purpose of this activity is to carry out basic experimental studies on a compact Paul trap configuration that simulates the collective processes and nonlinear transverse dynamics of an intense charged particle beam propagating over large distances through a periodic focusing quadrupole magnetic field. The planned experimental studies will include detailed investigations of beam mismatch effects and envelope instabilities; collective wave excitations; chaotic particle dynamics and production of halo particles; mechanisms for emittance growth; and effects of distribution function on stability properties.

Liquid metal Laboratory Study of MHD Effects on Surface Stability And Turbulence in Liquid Metal: A small-scale laboratory experiment has been initiated to study the fundamental physics of magneto-hydrodynamic (MHD) effects on surface waves and turbulence in liquid metal. MHD turbulence has been regarded as an essential element of many intriguing phenomena observed in space and laboratory plasmas, and it has been a primary subject of basic plasma physics research. Recent interest in the application of liquid metal to fusion devices also adds new demands to the understanding of MHD physics of electrically conducting fluids. This experiment uses easy-to-handle liquid metals, such as Gallium, which can be well approximated by MHD models. Three basic physics issues will be addressed: (1) when and how do MHD effects modify surface stability, either in linear regimes or nonlinear regimes such as solitary waves? (2) when and how do MHD effects modify a free-surface flow, such as by surface deformation? and (3) when and how do MHD effects modify thermal convection? Currently, MHD effects on surface waves are being studied and preliminary results on damping of driven waves due to magnetic field agree well with linear theory. A successful experimental investigation of these basic physics issues with detailed diagnostics would significantly advance our physics understanding of electrically conducting fluid, and therefore, the MHD nature of both laboratory and astrophysical plasma.

Laboratory Simulation of X-ray Spectra from Stellar Flare Plasmas: PPPL, in collaboration with LLNL, is using the NSTX plasma environment to simulate X-ray spectra from stellar plasmas under controlled laboratory conditions. We will use unique x-ray equipment to calibrate the spectral diagnostics of electron densities in the 10^{13} to 10^{14} cm^{-3} range. The spectral diagnostics of interest are those used to determine the densities of stellar flare plasmas from observations conducted with the newly launched Chandra X-ray Observatory and the X-ray Multi-Mirror Mission. Knowing the electron temperature and the emitting volume from other diagnostic systems the calibration of the density diagnostics will allow us to infer the plasma pressure in magnetic loops and thus the strength of the confining magnetic fields from the plasma beta. Measurements of high resolution X-ray spectra, including dielectronic recombination, have already been used to validate theoretical calculations by the Harvard Smithsonian Chandra group.

Hall thruster Studies of the Effect of Segmented Electrodes on Physical Processes and Fundamental Limitations of Hall Plasma Thrusters: A critical component of satellite technology is the propulsion system that maintains the position of orbiting satellites or transfers the satellite between orbits, including eventually decommissioning defunct satellites. A promising propulsion means is the Hall thruster, which employs magnetized electrons in crossed electric and magnetic fields, where the magnetic surfaces are also equipotential surfaces, acting as virtual grids for electrostatic acceleration of unmagnetized ions. Further development of Hall thrusters, including the very important issue of reducing plume divergence, will rely on advances in the basic understanding of plasma in crossed electric and magnetic fields. The research seeks to extend the scientific understanding of Hall thrusters or, more generally, the insulating properties of magnetized plasma, thereby to develop novel and superior Hall thruster technology. Our preliminary experimental investigations show that segmented electrodes along the channel, which make the acceleration region as localized as possible, can provide substantial reduction in plume divergence. We plan to research a family of segmented electrode Hall thrusters operating in the range of 1 kW, with the object of understanding the fundamental physics underpinning their operation. In the process, we will develop methods of localizing steep voltage drops that potentially challenge accepted limits on the magnetic insulation properties of plasma. It is a related objective to characterize the waves and instabilities that arise as these limits are approached. Finally, it is our objective to develop, on the basis of these investigations, better configurations for Hall thrusters.

The 5 year strategy for the Plasma Science and Technology Department is to:

- Develop new proposals for small-to-medium sized plasma experiments for OFES and/or other funding sources such as the NSF and BES. These proposals range in scope from basic plasma physics experiments to fusion concepts developments.
- Strengthen PPPL participation in heavy ion fusion research, including increased analytical and numerical efforts on beam-plasma interaction in the target chamber, and the initiation of experimental activities that make effective use of PPPL's established experimental capabilities and off-site heavy ion fusion facilities.
- Strengthen the connections between plasma science at PPPL and other branches of basic science such as high energy physics and space physics.
- Develop new projects within the Applications Research Division, such as Plasma Surface Sterilization. This involves a new technique being investigated by PPPL to create a plasma in the region to be sterilized, which has the potential to kill bacterial spores in a time period, sufficiently short to make the process applicable for use on food container filling lines.
- Expand PPPL's support to smaller US university programs in plasma science through mutual site visits by physicists, technological support by PPPL engineers, and joint proposals.

III.F.1 Technology Transfer

The Technology Transfer effort under the Plasma Science and Technology Department, actively promotes the application of plasma science and other technologies from across the Laboratory to needs within US industry, government and academia. PPPL seeks opportunities that enable the Laboratory to enhance its capability through research efforts funded primarily by the external sponsors. PPPL aligns itself with other institutions that can augment and complement the Laboratory's strengths in order to expand opportunities. PPPL also has, in the past several years, developed capabilities in a number of applications areas that are attractive to industry, and is actively seeking to leverage opportunities from those existing skills and accomplishments.

The mechanisms that are available to carry out the Technology Transfer mission are Cooperative Research and Development Agreements (CRADAs), Work-for-Others (WFO) arrangements, Personnel Exchange agreements, and Technology Maturation efforts.

The Laboratory continues to actively solicit outside support for projects that fit into the goals envisioned for the Laboratory's institutional development. The Laboratory continues to encourage researchers within PPPL to become involved with externally funded research, and to respond to inquiries from potential sponsoring partners.

The Laboratory's Head of Technology Transfer is on the Executive Board of the Federal Laboratory Consortium (FLC). The FLC is a Federally sponsored agency that provides a forum for the Federal Laboratory Technology Transfer Personnel to learn from each other, and to share resources and opportunities. The Laboratory maintains close contact with other DOE Energy Research Laboratories on matters related to Technology Transfer, and attends appropriate DOE meetings and participates in working groups involved with Technology Transfer issues and policies. The

Laboratory's Head of Technology Transfer also Heads the PPPL Patent Committee, and reviews each invention disclosure for potential technology transfer applicability. The Head of Technology Transfer also works closely with PPPL inventors and with the Princeton University Office of Research and Project Administration to identify and promote the licensing of Laboratory developed technologies, and to find outside sources of support for PPPL non-fusion inventions.

III.G. Theory and Computation

The PPPL Theory Department continues its leading role in helping the fusion energy science program achieve improved scientific understanding of the physics of plasmas and fusion devices. In recent years, improvements in theoretical and computational tools, as well as improved plasma diagnostics, have made possible much more comprehensive comparisons of experimental results from confinement devices with detailed theoretical models. This has advanced scientific understanding dramatically and has stimulated the development of new concepts and of innovative methods for improving performance. There is also an increasing trend to transfer knowledge and methodology developed in the mainline fusion area to investigate alternative paths to fusion energy and to non-fusion plasma applications.

Theoretical activity at PPPL covers a wide spectrum from very fundamental to quite applied. Fundamental studies of the properties of plasma form a base for the applied studies to build upon, and provides recognition and enhanced opportunities to interact and share ideas with scientists in other related disciplines. The applied theoretical studies now form the basis for interpreting data from experiments, and for developing new fusion and non-fusion plasma concepts. PPPL expects to maintain strong theoretical programs in each of the following areas.

Fundamental Plasma Theory: Since the Laboratory's inception, scientists at PPPL have played a major role in providing plasma sciences with excellent theoretical foundations. PPPL is further developing the fundamental theory of plasma turbulence, and is developing new representations to allow efficient nonlinear computation of the evolution of macroscopic properties of plasmas. It has also pioneered the hybrid (fluid/kinetic) analysis capabilities needed to study the behavior of energetic particles in fusion-grade plasmas. Another area of renewed activity is that of the theory of magnetic reconnection. A better understanding of this fundamental process will have applications to both laboratory and astrophysical plasmas.

Tokamak Theory: While significant progress has been made in understanding the tokamak configuration, there remains much work to be done before a truly predictive model is available. The gyrokinetic and gyrofluid models of the tokamak have had considerable success in their predictions of key ion confinement properties that have been experimentally supported. However, electron confinement remains an outstanding problem. Advances here will require a more realistic description of electron physics and electromagnetic effects. The prospects for accelerated progress can be greatly enhanced by the utilization of powerful massively parallel computers. In order for tokamaks to evolve to a much more attractive fusion reactor, a better theoretical understanding of such features as the conditions for transport barrier formation is needed. In the area of MHD and macroscopic stability of tokamaks, our understanding of the onset criteria and the linear phases of the most destructive tokamak instabilities is now quite reliable. Computer codes developed at PPPL and elsewhere are routinely used to interpret experimental data and design new experiments with high confidence. Two dimensional MHD simulation codes have been well calibrated and are now used as engineering tools for developing new plasma control techniques and accessing new operational regimes. Present emphasis in the MHD area is on (1) extending this high-level of confidence to the prediction of the non-linear saturation of fully three-dimensional plasma instabilities, (2) developing techniques for the active stabilization of MHD modes, (3) developing effective modeling of slower (non-ideal MHD-time-scale) instabilities such as neoclassical tearing modes and resistive wall modes. The associated resistive and kinetic dynamics here hold the key to accessing and maintaining a sufficiently high pressure (high-beta) plasma for long times. Certain critical burning plasma issues, such as conditions for the onset of energetic particle driven MHD modes, and the practicality of transferring the fusion-product energy directly to the plasma ions (alpha channeling) with the possibility of driving plasma current, remain under investigation.

Theory of Alternate Confinement Configurations: A significant portion of the activity in theoretical analysis of confinement systems at PPPL has shifted from the tokamak to other promising configurations. With the on-site presence of the National Spherical Torus Experiment at PPPL, the spherical torus, will continue to receive much attention. Many attractive features of the ST have been identified theoretically, including regimes of high performance and regimes where very little external current drive would be required to sustain the configuration. This work will intensify as more experimental results from NSTX become available. Similarly, there is great interest and excitement in the investigation of novel stellarator configurations. Theoretical studies have identified attractive configurations called quasi-axisymmetric (QA) and quasi-poloidal (QP) stellarators. These innovative designs are expected to provide compact configurations with high-power density and good confinement while at the same time targeting freedom from plasma disruptions and minimum recirculating power. A major optimization code development effort at PPPL has enabled the successful design of the NCSX (National Compact Stellarator Experiment) which include the design of an optimized set of stellarator coils taking into account their impact on plasma pressure and current limits flux surface quality, and transport properties – while simultaneously meeting constraints of engineering practicality. Other exploratory studies related to the Field Reversed Configuration (FRC), the liquid-lithium wall tokamak, inertial fusion energy (IFE), and laser/plasma interaction, are being actively pursued. New computational tools are enabling the study of these configurations at a depth not previously possible. For example, in the FRC studies, the identification of operating regimes exhibiting more favorable confinement properties has been enabled by the development of a new 3D hybrid simulation capability which includes a kinetic large-orbit treatment of ions

Non-Fusion Applied Plasma Theory: The area of non-fusion applications of plasmas continues to grow and is increasingly reliant on theoretical guidance. Plasma-based accelerators may prove to enable much more cost-effective and compact high-energy particle accelerators. The application of powerful plasma simulation techniques to nonlinear beam dynamics is already having an impact in particle accelerator design and optimization. Space plasma physics is becoming increasingly important with the wireless communication revolution that has occurred, and with the wealth of data from satellite observations that needs interpretation. Research on important solar and astrophysical phenomena (coronal heating, accretion disk dynamics, etc.) are being actively pursued. Other applications, such as plasma display panels and plasma diagnostics to monitor the manufacture of fibers, are important spin-offs of plasma science and fusion research which take advantage of advanced theoretical support.

Collaborations

A goal of the PPPL theory program is to continue and strengthen productive collaborations with other prominent national plasma science programs including those at General Atomics, the Massachusetts Institute of Technology, the University of Texas Institute of Fusion Studies, Lawrence Livermore National Laboratory, and Los Alamos National Laboratory as well as with international institutions such as the Japan Atomic Energy Research Institute, the Joint European Torus in the U.K., the National Institute for Fusion Studies in Japan, the Max Plank Institute for Plasma Physics in Germany, Culham Laboratory in the United Kingdom, Cadarache Laboratory in France, the Ecole Polytechnic Federal of Lausanne Switzerland; and with individual scientists from university programs such as the University of California San Diego, Los Angeles, and Irvine, the University of Maryland, New York University, Columbia University, the University of Colorado, and Cornell University. With the broader focus on innovative confinement configurations, collaborative linkages have been strengthened with the international stellarator community and with national initiatives on stellarators, ST's, and FRC's. PPPL also collaborates with many of the above institutions on several national computational projects. These include MHD, Microturbulence projects within the Fusion Energy Sciences component of the DOE SciDAC (Scientific Discovery through Advanced Computing) Program, the National Transport Code Collaboration, as well as the aforementioned lead role in the Plasma Science Advanced Computing Institute.

Finally, motivated by the urgent need to help attract, train, and assimilate the best and brightest young talent into the field, the Theory Department actively participates in the education program at Princeton University. In addition to those individuals serving on the faculty, many members of the group have provided support to the program by serving as thesis research advisors. This has been mutually beneficial in that the Laboratory provides an exciting array of frontier research opportunities, while Princeton University provides a steady stream of extraordinarily well-qualified and energetic students. The teaching program also provides many opportunities for the PPPL Theory staff to interact with faculty and students in other related departments at Princeton University.

Computational Plasma Physics Group

The Computational Plasma Physics Group (CPPG) consists of both computational physicists and computer science professionals who combine expertise in physics, computer science, and software engineering. This group's charter is to foster the extension and development of modern computational analysis in support of fusion science research. The computer professionals are assigned to the areas of parallel programming, high-end visualization, graphical user interface development, software support, documentation and user support, as applied to specific physics research codes. The computational plasma physics group activities have the following thrusts:

- Streamline, modernize, and extend existing physics modeling, data analysis and machine design codes to improve performance, usability, accessibility to the wider fusion science community, and applicability to a wider range of research problems.
- Develop new methods and standards for on-line and between-shot experimental data analysis, which could be utilized by NSTX, DIII-D, C-Mod, and other tokamaks, and eventually extend these methods and standards to stellarators and/or other innovative confinement configurations.
- Enhance development of the major PPPL simulation codes by facilitating their implementation on parallel computers, while extending their physics and improving their user interface and visualization capabilities.
- Support the development and the application of the TRANSP and TSC integrated modeling codes, and share reusable components of these codes via the NTCC modules library.

This group has accelerated the use of modern computer techniques and high-performance computing at PPPL and naturally complements the existing strong theory and experimental groups at PPPL. The CPPG helps to attract visitors and collaborators, thus fitting naturally into the leadership mission of PPPL. It is also an excellent vehicle for interacting with other disciplines, including academic departments at Princeton University, and for developing presentations at multi-disciplinary computational physics conferences. An excellent example of productive alliances with Princeton University academic departments is the sharing of a modern 128-processor SGI Origin 2000 computer that has produced exciting results accelerating PPPL's progress in high performance computing projects. The graduate program at PPPL also serves as a natural vehicle to effectively disseminate specialized computational physics knowledge outside of PPPL. A significant recent collaborative initiative in this area involving PPPL and Princeton University is the PICASSO Program (Program in Interactive Computer and Applications Science) led by the Computer Science Department. This program has received a 4-year $2.7M NSF grant to support graduate student internships in applied scientific computing, focused on scientific problems emerging from a number of different University Departments, as well as PPPL.

The CPPG also develops and oversees several computer hardware facilities at PPPL that are used for both general-purpose and medium-scale scientific computing. These facilities complement those available to PPPL at NERSC. There is increasing use of high-performance workstations at PPPL to perform the general-purpose scientific and engineering computing that was formerly done at NERSC on the vector computers there, but is now being phased out. This change has come about largely because the newest workstations available now are faster on most scientific applications than are the current vector "supercomputers" at NERSC, and are also considerably more cost effective. PPPL supports a Linux Beowulf cluster, PETREL, which now has 68 processors and is being upgraded to 200 by Sept 02. This is used both for single-processor and parallel applications, and as such complements the facilities available at NERSC. The 20 processor PARED facility is closely linked to the high-resolution visualization wall described below and as such is used primarily to develop and apply parallel visualization techniques to scientific applications. The highest-end IBM-SP massively parallel computers at NERSC are presently being utilized for the most advanced 3D microscopic and macroscopic simulation projects at PPPL.

In collaboration with the Computer Science Department of Princeton University, the CPPG has constructed a high-resolution display wall for advanced visualization applications. It presently utilizes 12 separate back-projection projectors that are coordinated to produce a single large high-resolution display. This wall is used to visualize complex simulation and experimental data with fractal structure that make use of its high-resolution capabilities. Research collaborations with several other Laboratories are targeting the development of parallel drivers for the display wall to enable rapid manipulation of the data. The CPPG is also actively engaged in the new Fusion Collaboratory within the DOE Office of Science's SciDAC Program.

In connection with the SciDAC work, CPPG is actively exploring the possibilities of sharing of computational resources securely over the network, using GRID computing methodologies as developed by the Globus group at ANL, the CACTUS group in Europe, and others. Under auspices of the Fusion Collaboratory, the PPPL TRANSP code is being deployed as a computational service on the GRID, and will be directly accessible to a worldwide user group.

PPPL has recently been funded to begin investigations leading to a Topical Computing Facility for Fusion Energy Science. The prototype facility will be a 128 processor cluster system with a fast interconnect, which will support a number of the SciDAC projects, as well as the Fusion Collaboratory. In collaboration with the Oak Ridge National Laboratory this project will determine the most effective architecture(s) for fusion codes, experiment with GRID computing for fusion and develop large-scale between-shots data analysis capabilities in support of experiments. Possible linkages to Princeton University and the Geophysical Fluid Dynamics Laboratory, located close to PPPL, could lead to an opportunity for very considerable computational resources that could be applied to PPPL's missions.

III.H. Science Focus Groups

Science Focus Groups have been established to coordinate scientific efforts in the five major fusion science areas that are key to the eventual realization of an attractive fusion reactor concept: Turbulence and Transport; Macroscopic Stability; Wave-Plasma Interaction; Fast Particle Physics; and Plasma-Boundary Physics. These groups are situated on the Organization Chart in such a way that they link Theory and Experiment. The major goal of these groups is to foster communication and coordination amongst Laboratory programs, both on-site and off-site in each of the scientific areas. They provide a key review role in planning for Projects and Theory within the Laboratory. The role of the Computational Plasma Physics Group, which also links theory and experiment, is to help assure that advances in computational capability are effectively applied to experimental data analysis codes and to the development of predictive theory codes, which can lead to optimized tokamak performance and proof-of-principle innovative confinement configurations.

A key additional role for the Science Focus Groups is to foster improved connections with non-fusion science areas through publications in non-fusion journals, through lectures at non-fusion institutions, and through directed efforts to form research alliances.

III.I. Laboratory Program Development Activities

The purpose of the Laboratory Program Development Activities (LPDA) is to stimulate creative research activities within PPPL involving top quality science with good potential for attracting external support in the future. Each year as part of the budget process, the Laboratory submits an LPDA plan and funding request to OFES for review and approval. At the end of each fiscal year, the Laboratory submits an a summary report on its LPDA activities to OFES. In addition to work in the fusion area, LPDA importantly involves research in allied areas which enable a broadening of PPPL research activities and stimulates healthy cross-fertilization of ideas. In every case, however, a decisive factor is the degree to which an activity contributes to the achievement of PPPL's missions. A good example of success is the LPDA-supported research in Magnetospheric Space Plasma Physics, which is now supported significantly by NSF and NASA, and is stimulating strong cross-fertilization of ideas between space and laboratory plasma physics. Requests for proposals for LPDA activity are sent to Laboratory staff at the beginning of each fiscal year. Proposals are peer reviewed and the limited funding distributed to those projects with the best potential. Examples of projects funded in FY02 include:

Project (Investigator)
Advanced Lithium Wall Coatings for Fusion Experiments (Majeski)
Assessment of a Burning Plasma in an ST (Ono)

Dynamic Modeling of Neurophysiological Experiments for Space Plasma Systems (Johnson)
Investigation of Investment Castings (Heitzenroeder)
Initiate Development of a 3D Kinetic Fluid Simulation Code (Cheng)
Magnetized Plasma Source (Fisch)
Numerical Modeling of Hypersonic Fluid Flows (Okuda)
Rotating Gallium Disk (Ji)

III.J. Education

III.J.1. Science Education Program

The mission of the Science Education Program is to leverage the human, scientific, and technological resources of PPPL to:

- Begin training the next generation of scientists and engineers.
- Provide opportunities for students and teachers to engage in scientific inquiry in ways that enhance their understanding of science concepts and thinking.
- Provide innovative opportunities for educators to work with scientists and engineers to enhance science teaching and learning. Reach out to all students and teachers, particularly those previously excluded from educational opportunities.
- Advocate US science and math standards.
- Improve the scientific literacy of the community at-large.
- Communicate current scientific knowledge, including that about fusion energy sciences, to members of the community using modern communications technology.

Programs include:

- Partnership with Trenton Public Schools, a collaborative effort to improve math, science and technology education in the district. A key objective of the partnership is to expand the teachers' knowledge of science and math concepts, and to assist them in presenting the material in a way that engages students.
- Summer Teachers Institute and Science Over Supper provide staff development to elementary and middle school teachers, and are designed to enhance their science knowledge and ability to conduct creative, engaging, inquiry-based lessons.
- Summer Institute in Plasma Physics and Fusion Energy for high-school teachers provides an opportunity for teachers to gain an in-depth knowledge of plasma science and to develop classroom applications.
- National Undergraduate Fellowship Program, gives outstanding undergraduate students in US colleges and universities an opportunity to participate in projects at the forefront of R&D of fusion energy.
- Energy Research Undergraduate Laboratory Fellowship Program, a national program designed to provide educational training and research experiences for academically talented, undergraduate students.
- Undergraduate and high school student research opportunities that enable students to work with mentors to participate in the on-going research at PPPL.
- IPPEX, an interactive web page which includes subjects on electricity, magnetism, energy, and fusion. Experimental data from fusion can be used in optimizing the fusion reaction and studying the fusion physics.
- National Science Bowl, a regional competition hosted by PPPL for high school students. The top regional winner goes on to compete in Washington, D.C.
- Science on Saturdays, a series of free lectures geared towards high school students on selected topics at the forefront of research from a variety of disciplines. This draws on speakers from the laboratory, from the wider fusion community, and from the rich Princeton-area scientific community.
- Expanding Your Horizons Mini-Conference, the goal of the program is to introduce middle and high school girls to careers in science and technology. The program includes workshops and presentations by female scientists and engineers from PPPL and the surrounding scientific community.

Over the next five years, the Science Education Program will:

- Continue undergraduate research experiences by enhancing the educational value of the programs and increasing the diversity of participants.
- Continue partnership activities that focus on staff development for teachers and enhanced learning opportunities for students, and that provide opportunities for researchers to interact with teachers and students in ways that effectively enhance science learning.
- Continue to support the science education reform efforts undertaken by school districts and to partner with other businesses, industries, and other organizations to catalyze these efforts.
- Continue to offer opportunities for students to experience the richness of the Laboratory environment, and offer and participate in projects such as Science on Saturday and the National Science Bowl.
- Seek creative and innovative ways to make the research work of the Laboratory accessible to teachers and students at all levels in ways that are meaningful and that encourage development of scientific thinking. The Internet and other technologies will be an important part of this effort.

III.J.2. Graduate Education

The Graduate Plasma Physics Program was first offered at Princeton University in 1959 and two years later was incorporated into the Department of Astrophysical Sciences. In an environment that has seen enormous changes in the fields of plasma physics and controlled fusion, the Program has consistently focused on fundamentals in physics, computational physics, and applied mathematics and on intense exposure to contemporary experimental and theoretical research in plasma physics.

Graduate students entering the Plasma Physics Program at Princeton University spend the first two years in classroom study, acquiring a firm foundation in the many disciplines that make up plasma physics. Many of the required courses are taught by the members of PPPL's research staff, including three Princeton University Professors, who comprise the sixteen-member plasma physics faculty. The curriculum is supplemented by courses offered in other departments of the University and by a student-run seminar series in which PPPL physicists share their expertise with the graduate students.

Most students hold Assistantships in Research at PPPL through which they participate in the Laboratory's experimental and theoretical research programs. In addition to formal class work, first- and second-year graduate students work directly with the research staff, have full access to Laboratory and computer facilities, and learn first-hand the job of a research physicist.

First-year students assist in experimental research areas, while second-year students assist in theoretical research. After passing the Department's General Examination, at the end of their second year, students concentrate on the research and writing of a doctoral thesis, under the guidance of a member of the PPPL research staff. Completed dissertations during FY01-02 are shown in Table 13.

Six students in residence during FY02 held prestigious fellowships: four Fusion Energy Sciences Fellowships, one Hertz Fellowship, and one Princeton University Honorific Fellowship. Some of these fellowships are supplemented by partial research assistantships.

Overall, the PPPL graduate studies program has had a powerful impact on the field of plasma physics and related disciplines. Over two hundred scientists have received doctoral degrees from Princeton through the Program in Plasma Physics. Many have become leaders in plasma research and technology in academic, industrial, and government institutions. This process continues as the Laboratory trains the next generation of plasma scientists and engineers, preparing them for the many diversified challenges of the next century.

In addition to the Plasma Physics Program in the Department of Astrophysical Sciences, the Graduate Program in Plasma Science and Technology is based within the University's School of Engineering and Applied Science. This program provides support for students pursuing degrees within other departments, but who conduct plasma applications research, such as plasma etching of silicon semiconductor devices or plasma deposition of thin-film.

III.K. TFTR D&D and Caretaking

Following the conclusion of the experimental program in April 1997, TFTR systems were shut down, electrically and mechanically “safed” and put into a caretaking routine. The scope of work for this phase was defined in a formal Statement of Work agreed between the Laboratory and the DOE. Maintenance and surveillance of mothballed equipment have been required throughout the caretaking period. Vacuum volumes have been periodically monitored to measure tritium out-gassing and to perform pumping and purging operations to reduce these tritium concentrations. The Torus Cleanup System, Tritium Storage and Delivery Cleanup System, and Gas Holding Tanks have remained operational to process the tritium. The HVAC systems and the Liquid Effluent Collection system remain operational with an appropriate level of surveillance. Operation of the Radiological Environmental Monitoring Laboratory and Health Physics oversight of caretaking activities continues. Caretaking activities such as these will be largely, but not completely, eliminated with the conclusion of the TFTR D&D project in FY 2002.

TFTR Decontamination and Decommissioning

The deuterium-tritium operations resulted in the TFTR machine structure becoming radiologically activated, and plasma facing and vacuum components being contaminated with tritium. The primary objective of the TFTR Decontamination and Decommissioning (D&D) Project was to bring a timely and cost-effective closure to the TFTR Project and provide a facility available for the construction of a new Department of Energy experimental fusion device. The TFTR D&D Project covers the removal operations for the tokamak and remaining activated/contaminated components from the TFTR Test Cell (excluding the neutral beam injectors) and contaminated items from the Test Cell Basement. The tritium systems will be mothballed and left in place for use with a future experimental device designed to utilize tritium as a fuel.

The D&D effort began in FY00 and will be completed in FY02. The first stage of the D&D Project included the identification and removal of items desirable for future use. The second stage of the D&D Project was the removal of items from the Test Cell and contaminated items from the Test Cell Basement. Expertise and technology from the nuclear fission industry have been utilized, wherever possible, to safely dismantle activated and contaminated systems. The D&D plan was developed to provide cost and schedule estimates based on a conservative approach of dismantling, cutting, and packaging components, and shipping them to a DOE waste repository.

The radioactive material inventories for TFTR components have been classified as Class A Low Level Radioactive Waste. The total neutron induced radioactivity inventory disposed of was less than 700 Curies. The total amount of radioactive waste generated during D&D, including stabilizer and void space filler, was less than 2500 tons.

The D&D process has been documented via papers and photographs. A workshop to disseminate this information was held June 2002. By documenting this process, this information will be available for future fusion device design and D&D considerations.

Upon the conclusion of TFTR D&D activities, remaining TFTR components and systems will be assigned responsibility to the NSTX Project in support of machine operations. Remaining systems and tritium legacy activities, including the tritium systems and environmental monitoring, will be covered by other Laboratory funding (including G&A). At this time it appears that the D&D project will be completed on schedule.

IV. Summary of Major Initiatives

PPPL is proposing one major initiative: The National Compact Stellarator Experiment (NCSX). This project is included for funding in the President's budget for FY2003. Two other significant projects are under consideration, but are not yet ready for formal proposal. One would be a major enhancement of advanced computing for fusion energy sciences, including potentially a Topical Computing Facility (TCF) for Fusion Energy Sciences, and another would be a Next –Step Spherical Torus (NSST). While the TCF could be implemented within the time-frame of this Institutional Plan, only design work could be anticipated for the NSST. A description of each is provided in the following sections.

Initiatives are provided for consideration by the Department of Energy. Inclusion in this plan does not imply Departmental approval of, or intent to implement an initiative.

IV.A. National Compact Stellarator Experiment

A new experimental facility, the National Compact Stellarator Experiment (NCSX), is now being designed and will be built at PPPL during the time span of this Institutional Plan. The NCSX is the centerpiece of a US proof-of-principle program to develop the physics of compact stellarators. Its mission is to acquire the physics knowledge needed to evaluate the compact stellarator as a fusion concept, and to advance the understanding of 3D plasma physics for fusion and basic science. It will test the quasi-axisymmetric stellarator (QAS) concept, which provides the opportunity to build upon the advances in both stellarators and tokamaks and to combine their best features. The NCSX will be sited at the Laboratory's C-site, making extensive use of a mature infrastructure and equipment (e.g., power supplies, plasma heating, and vacuum pumping systems) from previous experiments. In 2001, the project passed a Department of Energy Physics Validation Review, was designated a proof-of-principle experiment by the Fusion Energy Sciences Advisory Committee (FESAC), and in 2002 received approval of Critical Decision 0, Mission Need, from the Department's Office of Fusion Energy Sciences. The Department requested $11M in its FY03 budget submission to Congress to initiate the NCSX design and fabrication project. A highly successful DOE-SC "Lehman" Conceptual Design Review of physics, engineering, cost and schedule took place in May 2002. Title I design will begin in October 2002; equipment fabrication will in FY04; and operation will begin in June 2007.

The NCSX project is led by the Princeton Plasma Physics Laboratory in partnership with the Oak Ridge National Laboratory, and with other institutions collaborating. To date, Auburn University, Columbia University, Lawrence Livermore National Laboratory, New York University, Sandia National Laboratories at Albuquerque, the University of California at San Diego, the University of Texas at Austin, and the University of Wisconsin have collaborated in the design. Stellarator researchers in Australia, Austria, Germany, Japan, Russia, Spain, Switzerland, and Ukraine have contributed to the project through international collaboration.

Compact Stellarators

The attraction of compact stellarators is their promise of providing a compact (low aspect ratio) high-beta plasma that does not disrupt and can be steady-state without external current drive or feedback control systems. Its potential is supported by theoretical analyses and the successful designs of experimental devices. The next step, experimental testing of compact stellarator physics, is the purpose of the national stellarator program and NCSX. The NCSX will test the quasi-axisymmetric stellarator (QAS) concept, which is based upon theoretical work by A. Boozer, J. Nuehrenberg, and P. Garabedian showing that stellarators, while three-dimensional in Euclidean space, can be designed to improve drift-orbit confinement by providing a direction of approximate symmetry of |B| in (Boozer) flux coordinates. The symmetry direction is toroidal (as in tokamaks) in the QAS. This provides good fast-ion confinement and low neoclassical transport losses, allows undamped flows to stabilize turbulence, allows self-generated bootstrap currents to generate some of the rotational transform, and is best suited for combining tokamak and stellarator physics. Tokamaks have demonstrated excellent short-pulse plasma performance in "compact" geometries, with aspect ratios (ratio of the plasma major radius to the average minor radius) usually less than 4. Stellarators have demonstrated levels of performance (energy confinement time up to 0.3 s, confinement enhancement factors up to 2, betas greater than 3%, electron temperatures up to 4.4 keV) approaching those of tokamaks, generally at aspect ratios in the range of 6-12. The QAS takes advantage of the tokamak's excellent confinement, ability to control turbulent transport, and lower aspect ratio to reduce development costs and system size. It uses the stellarator's externally generated helical field and three-dimensional shaping flexibility to passively stabilize the magnetohydrodynamic (MHD) modes (particularly the external kink and neoclassical tearing modes) that limit the pressure and pulse length in tokamak plasmas. This combination of features, if proven, would greatly improve the vision of a magnetic fusion reactor.

In addition, the NCSX will be used to advance the understanding of three-dimensional plasma physics effects that are of general importance for magnetic confinement fusion and basic plasma science. It will provide unique controls for investigating the effects of three-dimensional plasma shaping, of internally- and externally-generated sources of rotational transform, and of quasi-axisymmetry on the stability and confinement of toroidal plasmas.

NCSX Design

The NCSX has been designed around a coil system that is optimized to provide attractive plasma physics properties and experimental flexibility, subject to engineering constraints for affordable construction. The coils produce a free-boundary QAS plasma equilibrium with three periods, an aspect ratio $R/\langle a\rangle = 4.4$, and strong axisymmetric and three-dimensional shape components. It satisfies physics requirements for good quasi-axisymmetry, good magnetic surfaces, and stability to ballooning, external kink, vertical, and Mercier modes at $\beta = 4\%$. About one-fourth of the rotational transform at the edge is generated by the bootstrap current, while the remainder is generated by the coils. The shear direction is favorable for stability of neoclassical tearing modes. The high degree of quasi-axisymmetry means that there is a very low effective helical ripple and low calculated helical ripple contributions to the neoclassical transport. The coil system provides experimental flexibility needed to test the physics, for example the ability to vary the rotational transform, the shear, and the stability beta limit, while maintaining good quasi-symmetry. The coils provide good physics properties (quasi-axisymmetry, stability, and magnetic surfaces) over a wide range of beta, current, and profile shapes. Startup simulations demonstrate the evolution of the plasma, consistent with planned equipment capabilities, from an initial vacuum state to a high-beta target state along a stable path. These capabilities are provided with a practical coil design that includes realizable structure geometries and conductor properties and allows good access for plasma heating and diagnostics.

The NCSX will have a major radius of 1.4 m and a magnetic field (B) range of 1.2-1.7 T in the nominal configuration (>2 T at reduced rotational transform). It will be equipped initially with 3 MW of neutral beam injection heating power using two of the four existing PBX-M neutral beamlines arranged for tangential injection in a balanced (1 co, 1 counter) configuration. The remaining two beams can be added as upgrades to bring the NBI power to 6 MW. In addition, up to 6 MW of radio-frequency heating power from existing 20-30MHz source can be added by providing launchers and transmission systems. Fueling will be provided at first by a gas injection system which can provide feedback control on the density; pellet injection will be added later. High vacuum will be provided by an existing turbomolecular pumping system. A set of simple limiters will be installed initially, while a more extensive system of plasma-facing components, including divertors and pumps, are expected to be implemented over the life of the experiment. The vacuum vessel is designed to incorporate carbon plasma-facing components, bakable in-situ to 350 C. The facility will be equipped at first with diagnostics needed for shakedown of major machine systems, first-plasma, electron-beam mapping of flux surfaces. The machine design provides ample port access for diagnostics, which will be added during the operating phase of the program.

Plans for FY02 – FY07

NCSX Design and Fabrication Project. The conceptual design of the NCSX will be completed in FY02. Design and fabrication of NCSX, which is classified as a Major Item of Equipment, will start in October 2002 with the beginning of Title I design. The design will be developed by PPPL and ORNL engineers and scientists. The major stellarator core structures will be fabricated in industry. The stellarator core will be assembled by Laboratory staff. Reconfiguration of ancillary systems and infrastructure will be done by PPPL staff. Integrated system testing will be carried out as the last step in the project, culminating in First Plasma, scheduled for June 2007.

The design process for the modular coils and vacuum vessel, the most critical components, will include manufacturing development and prototyping. In the case of the vacuum vessel and modular coil winding forms, both the development and fabrication will be done in industry because of the special facilities and expertise required to make these large highly shaped structural components. The coils will be wound by PPPL taking advantage of in-house experience. The remaining stellarator core components, the TF and PF coils, support structure, and cryostat, are more straightforward and will be fabricated in industry.

The main components of the magnet power, neutral beam heating, and vacuum pumping systems already exist and were extensively operated in previous projects. The magnet power system will use the D-Site supplies formerly used on TFTR, while the neutral beams and vacuum pumping systems will be from PBX-M. The modifications needed to adapt them to NCSX are relatively straightforward and similar to past projects. They will involve a combination of procured components and services and in-house fabrication, assembly, and installation. The same applies to the site preparation and facility modifications work.

The central instrumentation and controls and data acquisition system will be largely patterned after the NSTX system which was recently implemented. This computer-based system will be assembled from procured components.

The NCSX baseline diagnostics will be based on proven techniques and detection technologies. The main development issues have to do with designing the interface to the stellarator device to provide optimum measurement capability in the complex stellarator geometry. This issue will be addressed by Laboratory physicists working with design engineers using CAD models to optimize the layout. Once these design and interface issues are resolved, implementation will be relatively straightforward and similar to past projects.

The Total Estimated Cost of the NCSX Major Item of Equipment project is $73.5M.

NCSX Research Preparation. During the period of NCSX design and fabrication, preparations for the research program will proceed. Activities in the first few years include planning of the research program to identify needed tools, application of theory-developed codes in the preparation of needed analytical tools, and preconceptual design of upgrade hardware to ensure compatibility with the machine design. Starting about 2 years before first plasma, conceptual design and long-lead fabrication of upgrade equipment will have to begin so that it will be ready when needed in the research program. These long-lead upgrade tasks are: diagnostics for the Ohmic phase; and plasma-facing components and diagnostics for the initial auxiliary-heating phase. The Ohmic phase will begin about 6-8 months after First Plasma, following the e-beam field mapping phase. The initial auxiliary heating phase will begin about 18 months after First Plasma.

Participation in the Quasi-Poloidal Stellarator (QPS) Project. The Laboratory is a collaborator in a smaller, complementary compact stellarator project, the Quasi-Poloidal Stellarator (QPS), a concept-exploration experiment to be constructed at ORNL. The QPS, like NCSX, is part of the national stellarator proof-of-principle program. Its purpose is to explore compact stellarator physics at very low aspect-ratio ($R/\langle a \rangle = 2.6$) and the quasi-poloidally symmetric stellarator concept. As a concept exploration experiment, the QPS is more limited in its scope (smaller size, lower performance, less heating and diagnostics) and cost compared to the NCSX. The project schedule is similar to that of NCSX. The Laboratory will collaborate in the QPS by providing physics and engineering support to ORNL in selected areas, and procurement of major structural components, taking advantage of experience gained on NCSX.

IV.B. Topical Computing Facility for Fusion Energy Sciences

The concept of advanced scientific computing as a major new tool for discovery, complementing experiment and analytic theory (and motivating advances in both), is now being advocated by multiple agencies, led by DOE and NSF.

Plasma science in general and the fusion energy program in particular are taking advantage of the exciting advances in modern computer technology. This is highly responsive to the focus of the Fusion Energy Sciences program, in that it will accelerate scientific understanding and innovation in fusion research by:

- Maximizing return on the major investments in existing national and international experimental facilities.
- Enabling more confident prediction of the capabilities of proposed future experimental devices.
- Providing otherwise unattainable insights into the behavior of complex plasma-physical systems, providing the basis for further innovation.
- Enhancing productivity via effective crosscutting alliances to other disciplines also exploring cutting-edge computational simulation approaches.

Fusion Energy Sciences Participation in the DOE Scientific Discovery through Advanced Computing Program:

The major goal of the Fusion Energy Sciences element of the SciDAC Program is to develop and deploy advanced computational methods, capable of making optimal use of multi-teraflop computing resources. This will support quantitative understanding of plasma behavior in existing fusion experiments, reliable prediction of the performance of future fusion devices, and rapid innovation which follows from deeper understanding. As evidenced by a long, published track record of excellence in scientific computing and in the utilization of supercomputers, the fusion research community is an acknowledged leader in computational simulation, of both magnetically and inertially confined plasmas. This community is well positioned and is already taking advantage of major advances in computing power. The establishment of the Plasma Science Advanced Computing Institute (PSACI) centered at PPPL to coordinate Fusion SciDAC activities is expected to further enhance these prospects.

The PSACI is a distributed national center of excellence in computational plasma science managed through PPPL with responsibility to OFES for coordinating the Fusion SciDAC projects and also for nurturing collaborations/connections with other areas within the Office of Science SciDAC portfolio. The PSACI management team and distinguished Program Advisory Committee are composed of leading scientists from a broad range of institutions both within and outside the plasma physics discipline. The funding has been handled in a peer-reviewed grant applications process managed by OFES.

Topical Computing Facility for Fusion Energy Sciences

Although most of the computing for SciDAC is currently being carried out on the large tera-flop computing platforms located at NERSC, there is an identified need for parallel topical computing facilities focused on specific scientific applications, such as Fusion Energy Sciences. PPPL has recently won an award for a Prototype Topical Computing Facility for Fusion Energy Sciences, and would be an ideal site for a major topical computer facility because of its lead role in the PSACI activities, its strong historical role in computational plasma physics, and its recent activities in developing a production scientific computing facility with alpha and Sun workstations, Beowulf clusters, and a modern visualization display wall (developed in collaboration with Computer Science Department of Princeton University). Currently the Laboratory is exploring possible linkages with the nearby NOAA Geophysical Fluid Dynamics Laboratory and Princeton University. PPPL has adequate facilities (power, HVAC, available space) to support a substantial new computing facility which would support the Fusion Energy Sciences research community, and provide strong linkages both to the climate community and the wider scientific community. The facility would be designed to run major fusion codes efficiently and to provide large-scale between-shots data analysis in support of the major experiments. It would need to interconnect, in a GRID sense, with the NERSC facilities as well as with satellite facilities at each fusion institution.

IV.C. Next-Step Spherical Torus

Due to the encouraging results from ST experiments such as NSTX and the MAST experiment in the U.K., an initial engineering and physics design assessment of a next-step spherical torus (NSST) device has begun. NSST is envisioned as a "performance extension" stage ST with the plasma current of 5 - 10 MA, a significant step from the present "Proof-of-Principle" devices with the 1- 2 MA capability. The primary mission elements of NSST are to 1) Provide sufficient physics basis at multi-mega-ampere plasma current range including solenoid-free start-up and sustainment to start the design and construction of a compact Component-Testing-Facility (CTF), 2) Explore advanced physics and operating scenarios of high bootstrap current fraction/ high performance sustained advanced ST regimes at multi-mega-ampere plasma current range, which scenarios can then be transferred to CTF, DEMO, and/or Power Plants, 3) Expand the existing tokamak data base at low aspect-ratio regime to further improve the theory and modeling understanding and predictive capability, and 4) Contribute to the general plasma / fusion science of high temperature (collisionless) high β toroidal plasmas for the Innovative Confinement Concept (ICC) as well as non-fusion plasma science including solar and space physics. NSST is envisioned as a national collaborative research facility with its research program formulated and carried out by a national research team. The NSST can utilize the TFTR site to minimize the time and cost of construction. If performance projections are met through the initial deuterium operations, the site also offers a tritium handling capability for NSST to enable alpha particle related physics in high beta ST plasmas for the first time. To support an accelerated fusion energy development path, the design and construction of the NSST facility will need to start in 2006. The NSTX research plan is consistent with providing the needed physics basis for a highly cost-effective NSST in this time scale.

V. Operations and Infrastructure Strategic Plan

V.A. Environment, Safety and Health

PPPL continues to maintain a strong program in Environment, Safety and Health (ES&H). This program continues to seek improvement based on operating experience, lessons learned and continued attention to elements of Integrated Safety Management (ISM).

In CY01, a significant amount of work was performed at PPPL requiring the radiation protection services of the ES&H and Infrastructure Department's Health Physics Branch. This work included removals of components close to the activated and tritium-contaminated TFTR vacuum vessel, and segmentation of the vacuum vessel itself as part of the TFTR D&D Project. Even with this intense radiological work in CY2001, there were no skin or clothing contamination events, and the total effective dose equivalent to our employees was limited to 7.42 person-rem. Both measures are considered "Outstanding" performance under our contract with DOE.

ES&H Goals and Issues

The ES&H policy of the Laboratory is to take all reasonable precautions in the performance of tasks to protect personnel, visitors, neighbors, property, and the environment from injury. From this policy, it follows that PPPL complies with all applicable federal, state, local and University ES&H regulations; actively encourages safety awareness on the part of its employees and visitors; and assesses and minimizes the risks inherent in its programs.

As one indication of the success of ES&H, PPPL measures OSHA statistics:

	Recordable Injuries		Away from Work Lost Work Day Cases		Away from Work Lost Work Days	
Cal. Yr	goal	actual	goal	actual	Goal	actual
95	2	1.29	0.75	0.86	15	10.11
96	2	1.33	1	0.83	15	5.32
97	1.5	1.88	1	0.51	15	7.69
98	1.5	1.47	1	0.21	15	0.63
99	1.5	3.04	1	1.14	15	29.30
00	1.5	3.72	0.5	0.51	15	0.85
01	1.5	5.08	0.5	0.79	15	31.76

In 2001, there was an increase in the frequency and severity of recordable injuries during the first half of the year due to weather-related and other factors. PPPL's injury and illness experience improved dramatically in the second half of 2001, with a >50% drop in the recordable injury case rate, and a 94% decrease in the number of away-from-work and restricted days. Initiatives are underway to increase awareness, skills, and safe work performance These initiatives include more frequent workplace inspections by line management and oversight personnel, enhancements of the lessons learned program, and instituting annual "stand downs" of work activities to involve workers in discussions on ES&H. Overall, the Laboratory's ES&H record has been good and PPPL will continue to strive for exemplary performance in this area.

Current Conditions

Integrated Safety Management at PPPL is accomplished consistent with DOE policy, requirements, and guidance in a manner that applies controls and precautions tailored appropriately to the hazards of the projects and work being performed. Although the term "integrated safety management" has only become prevalent in recent years, integrating safety into the management of work and into work practices has been the Laboratory's philosophy and practice for years. PPPL has conducted and will continue to conduct small group meetings with staff to review how PPPL implements ISM.

Periodic audits by internal staff led by Quality Assurance, and through Unified Safety Reviews and mini-reviews using teams of DOE and PPPL staff, verify implementation of the Laboratory requirements. PPPL also evaluates and responds to feedback from outside organizations such as DOE's EH-24. Corrective actions are developed and taken as appropriate.

The Environment, Safety & Health and Infrastructure Support (ES&H/IS) Department provides ES&H oversight and support, waste management, environmental restoration, site protection services, and quality assurance and control. Human Resources organizes the ES&H training in areas such as radiation safety, confined space, chemical safety, and electrical safety. Periodic management walk-throughs are conducted of Laboratory facilities by line management and ES&H personnel to reinforce the implementation of ES&H requirements by observing ongoing work activities. Facility Managers, consisting of representatives from the ES&H/IS and Engineering and Technical Support Departments, have been appointed to provide strong supportive leadership to line personnel in helping them fulfill their ES&H related responsibilities. Every geographical area of the Laboratory has a Facility Manager assigned.

The Laboratory continues to address the implementation of requirements using the "graded approach." PPPL reviews requirements and endeavors to institute procedures that address requirements in an efficient manner based on the unique hazards of the PPPL site. The Laboratory continues to work with other National Laboratories, relevant industries, and the DOE to develop and continuously improve its ES&H programs. PPPL also has made a commitment to DOE to help other laboratories with their ES&H programs as requested by DOE or the laboratory.

V.B. Communications and Trust

Fusion's promise is an energy source that will be better for the world and includes a facility that is safe and environmentally attractive. PPPL must assure that its research activities do not compromise that promise. As a result, activities are conducted under an environment, safety, and health program assuring that workers, the Laboratory's neighbors and the environment are equally protected.

The Laboratory has a number of methods to communicate and develop trust with the public. These include:

- A presence on the World Wide Web that allows anyone with computer access to obtain information on the Laboratory 24 hours a day. In addition, an individual can leave a message or a question, which is answered, in a short-time frame.
- Tours of the PPPL Facility. In addition to schools and the general public, PPPL has periodically conducted open houses inviting the public to view the facility.
- Meeting with local officials. Periodically, PPPL meets with local officials (municipal and county) to update them on the activities at the Laboratory and to answer their questions. The Laboratory also provides information and meets with the local environment council, regarding the PPPL activities.

- Reports. PPPL has detailed reports, such as the annual Site Environmental Report, which is made available to the public via the World Wide Web and in a public reading room at the local library.
- Presentations. PPPL personnel regularly go to schools and other organizations to present lectures on fusion and PPPL operations. In addition, Laboratory staff visit schools to conduct science experiments, judge science fairs, and assist in improving the process for teaching science and math at local schools.
- Mutual aid. The Laboratory has agreements with the surrounding municipalities to help when needed. As a result, our fire fighters have responded to a number of incidents off-site to help the local volunteers. Our health physicists have conducted radiation studies for municipalities that had concerns regarding specific hazards and responded to radiation events assisting the NJ State Police.
- Speakers Program. PPPL has researchers who address scientific and engineering professionals on aspects of PPPL plasma research. This action is an important component of communicating the community efforts in plasmas science and fusion research and development.
- Special Events. The Laboratory has colloquia, which are open to the general public. In addition, each year a series of "Science on Saturday" programs is held for high school students. These sessions often result in more than 300 individuals hearing a lecture on a current science topic.

PPPL continues to work with the local, county, and state governments to provide a value to the community and, as a result, build on the high trust level that currently exists for the Laboratory.

V.C. Management Practices

V.C.1 Human Resources

The Human Resources organization at PPPL provides expertise in support of the Laboratory's Science Program, managers and staff, Environment, Safety and Health program, Business Operations and in it's relationships with Princeton University, the Department of Energy, collaborators and stakeholders. As human resource professionals we partner with line management in the areas of recruitment, employee relations, compensation, staff training and development, benefits management and effective use of human resource technology.

As a group we meet periodically to discuss strategic directions for Human Resources and better ways of providing our services. One of the issues often discussed is the challenge we have over the next five years where the number of potential retirees at PPPL could possibly reach as high as 80-90 in number. This factor will affect the entire Laboratory as managers struggle to attract the best from a diminishing pool of qualified people.

One of the many challenges at hand centers around the nature of our work at PPPL which demands uniquely qualified workers whose competency is developed over time and typically on the job (staff composition is shown in Table 7). As staff retire they take with them many years of core competencies in specialty areas. Limited budgets will make it difficult to bridge from this level of experience. As a result of our reputation for excellence in research and our affiliation with a prestigious University, PPPL continues to be able to attract the candidates for employment particularly in the scientific and engineering disciplines. In the future, political events may impact our ability to bring scientists to PPPL as evidenced by changes regarding visa requirements for foreign visitors.

The Human Resources staff at PPPL will need to add to its burgeoning basic support functions and broaden its capabilities to develop a deeper knowledge of technology and its use of the Internet. As more organizations move toward Employee Self Service plans, we need to be technology trained and experienced moving ourselves and the staff from the traditional approach to benefits management. This will most likely happen over the next three years at PPPL.

We expect continued changes in employment law and requirements for compliance. This demand will increase our need for training classes to stay updated on the changes taking place in court cases brought by workers today.

As we get ready for continuing shifts in the traditional employment paradigm we know we will be engaged in vendor management; management of temporary workers; employee demand for increases in their quality of life and more leisure time off; management of retirees back in the work place; and all other non-traditional work forces.

Affirmative Action and Equal Employment Opportunity

PPPL developed and supported various programs and activities that demonstrate our sustained commitment to affirmative action, equal employment opportunity, and diversity. Achieving and sustaining a diverse workforce is a challenging goal for PPPL. Management regularly assesses the gaps between where the organization is now and where it needs to be relative to diversity. We also look for ways to design and implement strategies that close gaps, measure results, provide education and improve communications at the Laboratory.

- Provide each new hire with a comprehensive new hire package with benefit information along with various policies including EEO, affirmative action, sexual harassment and information about how to respond to racial and ethnic harassment.
- Developed web based diversity awareness training. PPPL staff can access information regarding the Laboratory's vision of diversity, goals and commitment, progress and achievements.
- Educate PPPL staff by inviting colloquium speakers to provide information regarding recruiting issues for women and minorities in Physics and other sciences.
- Establish relationships with colleges and universities in order to provide internship and employment opportunities for women in engineering.
- Maintain relationships with the employment staff on main campus in an effort to share information and resources.

The Laboratory's goal is to foster a positive work place where all employees feel included and respected; and where we make full use of the contribution of all employees.

V.C.2. Site and Facility Management

V.C.2a Description of Laboratory Site/Facilities

PPPL is located on a government-leased 88.5-acre tract of land on the Princeton University James Forrestal Campus in central New Jersey. The Laboratory utilizes ~ 730,000 square feet of space in Government-owned buildings located on "C" and "D" sites. Space distribution and facilities replacement values are displayed in Table 9 and 10. There are 28 buildings on C-Site and 7 buildings on D-Site.

The C-Site complex, including theoretical, administrative and research activities, experimental and technical operations, the Director's Office, and the DOE Princeton Group Office, is structurally sound. The D-Site complex, including experimental, office and support space built in the 1970's to support TFTR has largely been converted to support the NSTX experimental device. Adequate space exists for PPPL's smaller fusion devices, as well as for current and future non-fusion plasma science and technology projects. Recently, there has been increased demand for smaller Laboratory areas where Principal Investigators and/or students can conduct research. Office space is fully utilized and during certain peak periods in the summer office space is at a premium.

Presently, there are no known conditions that could seriously impact establishing new or expanding current missions. Three modular buildings (representing over 13,000 square feet) were demolished in FY00 and FY01. This effort has been part of a long-term plan since the mid-1990's to consolidate personnel and functions, and hence reduce reliance on high maintenance temporary facilities. The Laboratory Facilities Plan describes the existing site and infrastructure and planned construction for the next ten years. The condition, use and age of Laboratory facilities are shown in Figures 1, 2, and 3.

V.C.2b Laboratory Site and Facilities Trends

As Laboratory funding has declined over the past five years, maintenance funding as a percentage of replacement plant value has also declined. The operating budget for facility maintenance has been inadequate as measured against industry standards. Laboratory management has focused on this as an area requiring increased attention and is discussed further in section V.C.2.d.

V.C.2c Site and Facilities Plans

A modern, effective, and efficient physical infrastructure is of critical importance to maintaining PPPL's ability to continue world-class scientific research into the 21st Century. In response to an Office of Science initiative, a PPPL Strategic Facilities Plan Report was prepared in FY01 to meet the DOE Office of Science goal to modernize its laboratories by 2012. The modernization effort focused on:

- Mission – ensuring that facilities and infrastructure will be adequate to accommodate programmatic mission activities and technological changes.
- Worker Environment – ensuring that quality of facilities provides a preferred working environment for our researchers that help to attract and retain high quality staff.
- Environment, Safety, Health, and Security – ensuring that facilities and infrastructure provide a safe, healthy, and secure work environment for employees and visitors.
- Operations and Maintenance – ensuring that facilities and infrastructure will be efficient to operate and maintain.

The Strategic Facilities Plan was designed to build upon the PPPL Institutional Plan. The infrastructure needs in the Institutional Plan are largely driven by the research plans for the major projects (NSTX and NCSX) and our staffing projections. The research plans for NSTX, including planned upgrades, are developed on the basis of broad input from the user community annually at the Research Forum. The plans for the major projects are reviewed by Program Advisory Committees, which include members from the university community and have typically been chaired by scientists from the university community. In addition, the plans for the Laboratory are made available to the community at the Budget Planning Meeting, and a copy of the Institutional Plan is sent to the other leaders of the fusion community, which includes members of the university community. When the Institutional Plan is approved, it is posted on the web. This is how PPPL has involved the fusion community in developing our infrastructure plans.

Several of the primary considerations in facilities planning include:

- Fundamental site land uses will not measurably change from those represented today. The internal operating relationships of site functions may adjust or be altered to meet Laboratory missions and needs.
- The Laboratory staff size has decreased substantially from 1995 levels, but is expected to remain level (at approximately 400-500 FTEs including term employees and subcontractors), over the foreseeable future.
- A sequential rehabilitation effort will extend the useful life of aging facilities to the maximum feasible extent. Newer facilities will be altered consistently with changing missions and experimental needs.
- The basic infrastructure of underground utilities will not change in the long-range future. An important focus over the next ten years will be refurbishment (life extension) or replacement of sections of the utility system, especially in instances where there may be an increasing trend of failures.
- A sequential program of roadway rehabilitation will be coordinated over time. Nearly forty years of vehicle use and seasonal change have taken their toll on the roadways. A logical sequence of improvement will restore them. The on-site vehicular circulation pattern will remain essentially the same. Future site vehicular access will depend on projected Route 1 corridor traffic volume and access alternatives planned in coordination with development of the Forrestal Campus.
- The hardware and software for the physical security systems are of mid-1980 vintage and are becoming obsolete. Maintenance and replacement of materials and components is becoming increasingly difficult to resolve. A dedicated effort will be necessary to modernize, replace, or develop a substitute for the existing system. A DOE policy establishing security and safeguards as a direct funded activity has added an additional level of complexity to this situation.

V.C.2d Detailed General Purpose Facilities Plans and Facilities Resource Requirements

As Laboratory funding declined from 1995 through 1999, maintenance funding as a percentage of replacement plant value has also declined. The operating budget for facility maintenance was marginal during this period of cutback, and, as a result, the number of deferred maintenance items increased. Laboratory management has focused on this as an area requiring increased attention operating funding for maintenance requirements increased beginning in FY00 as part of a five-year plan provided to the DOE OFES in July 1999. In FY00, annual maintenance expenditures (excluding steam plant operation, landscaping, snow removal, and janitorial budgets) are approximately 1.1% of the facility Replacement Plant Value.

Maintenance priorities are established on a fundamental basis that relies heavily on the knowledge and experience of in-house engineers and technicians. Typically, 2000 to 2500 routine work orders are completed in a given fiscal year. Priorities are established to address work tasks that: (a) affect environment, safety, health or security issues; (b) are directly related to facility operations; (c) require immediate action to restore equipment to operable status; and (d) provide preventive maintenance to operate the facilities in an efficient manner.

PPPL uses Procedure GEN-009 "GPP Prioritization" for assessing and prioritizing proposed GPP Projects. The Technical Resources Committee is the final authority for establishing GPP Priorities and annual work plans. The TRC is composed of senior management representatives from technical, scientific, and administrative organizations within the Laboratory. The Maintenance & Operations Division serves as the focal point for collecting proposed projects. Proposed projects result from input from various organizations working at PPPL, but also as a result of facility assessments routinely performed by Maintenance & Operations. To facilitate the decision-making process, the TRC has formed a subcommittee, which is composed of subject matter experts from across the Laboratory to evaluate the merits of individual projects. This subcommittee uses criteria developed by the DOE for the Capital Asset Management Process (CAMP) to evaluate the proposed projects. It is important to note that the CAMP criteria is intended to be a tool for management to rank projects, but it is not intended to replace sound management judgment in reaching final decisions on project priorities.

The facility assessments by the Maintenance and Operations Division also provide a basis for strategic decisions regarding future site development. For example, facility assessments of several aging C-Site Buildings have led to the initiation of a conceptual design to study the benefits of erecting a single, new 3-story building and therefore eliminating 3 separate single-story buildings. The benefits include reduced operating expenses, a reduction in total building space, improved human factor considerations, and avoided costs for rehabilitating the older buildings. The conceptual design is scheduled to be completed in order to coincide with the FY05 budget planning cycle.

V.C.2e Assets and Space Management (Inactive Surplus Facilities)

PPPL Departments/Divisions are not charged for space utilization. The Maintenance and Operations Division and Facility Managers throughout the organization manage space. During FY02, property management personnel continued to review and dispose of property that is no longer needed to support current or planned PPPL operations. Laboratory management and project personnel continue to review site equipment and material to identify assets that are surplus to PPPL's needs. These reviews include assets in-use and held in storage, spare parts, and common-use stores inventory. The disposition strategy for property declared excess will be to apply assets to an ongoing or planned projects, distribute assets to other DOE labs or federal agencies, and donate or sell the assets through the General Services Administration's various disposition programs. The disposal of the excess and scrap property generated by the D&D of TFTR is ongoing.

V.C.2f Energy Management

The PPPL In-House Energy Management Program includes providing appropriate control, organization, planning, and administration of utility contracts, and providing direct liaison interfaces with utility companies. Electric power is, by far, the largest utility expense. PPPL's objective is to obtain the most competitive price for electric power that meets the reliability requirements of the experimental program. Electrical energy for PPPL is provided by Public Service Electric & Gas Company through a GSA Area-Wide Contract. The State of New Jersey has endorsed deregulation of the electric power market, and PPPL is working closely with DOE and the Defense Energy Support Center to explore avenues for procuring electricity.

In an effort to preserve operational funds by emphasizing energy conservation, Utilities Management custom designed and implemented the Laboratory Electric Utility Bill Apportionment Program, which directly charges major users for electrical usage. From the start, this program has been a success and has reflected monthly savings of 15-20% in the Laboratory's electrical cost. The Electrical Interrupt and Electrical Curtailment Service Utilities Programs have saved the Laboratory over $10 million since inception in FY86. These agreed upon demand credit savings occur monthly, whether PPPL's electricity is interrupted or not. It is noteworthy to point out that over the years, electrical interruptions were minimal and have not conflicted with the Laboratory's mission.

In order to reduce the electrical energy demand costs, custom software programs have continued to operate special Demand Monitor Access Terminal(s). The Utilities Demand Monitoring System provides opportunity and capability to control electrical demand (kW) and energy consumption (kWh) costs, thereby achieving cost efficiency. PPPL also implements a maintenance program to ensure the efficient operation of buildings and timely correction of deficiencies. The Building Automation System has received upgrades and efforts have commenced to incorporate additional buildings and equipment into the system for even greater energy saving opportunities.

PPPL's In-House Energy Management Program resulted in a reduction of 28.5% in building energy consumption per SF in FY01 vs. the FY85 Base Year. This compares with a National Energy Conservation Policy Act goal of a 20% reduction between FY85 and FY00 and the goal of 40% by FY05.

V.C.3 Security, Intelligence & Nonproliferation

PPPL strives to ensure that its employees, collaborators, visitors and the general public work or visit a safe and secure environment through an Integrated Safeguards and Security Management approach. PPPL’s Security Program is designed to protect its assets, intellectual, property, computational and other institutional resources ensuring that its scientific mission and operational requirements as a DOE National Laboratory are sustained. PPPL updates its Site Security Plan annually. The Plan addresses potential threats and targets, identifies protection strategies and physical protection systems, protective forces, information security, property protection, and risk assessment activities.

The task of providing protection for DOE sites and facilities continues to become increasingly complex due to the rapid changes that are taking place in the world. These recent changes have made it clear that PPPL is among Laboratories and other federal facilities reassessing security countermeasures to provide requisite protection for facilities, staff, and visitors. The events associated with September 11, 2001 resulted in a significant impact on the Laboratory's Security Program. In accordance with established DOE protocols, heightened security controls were immediately implemented and have been in effect ever since. These controls included additional security patrols, enhanced access controls, and several modest facility improvements. Due to the timing of the event, there was insufficient budget authority to cover the costs of these necessary enhancements. PPPL has worked closely with the DOE on the budget issue, unfortunately, the funding concern continues to exist for the forseeable future.

In addition, the Laboratory has proposed incremental funding ($1.3M) to replace an aging and deteriorating facility access control system. The proposal has been reviewed and endorsed by SC Security personnel for funding consideration.

PPPL's fundamental research subject areas are generally available in the public domain for civilian science purposes and aligned to university disciplines. Because PPPL does not conduct classified research or maintain classified information, the Laboratory is exempt from the Unclassified Foreign Visits and Assignments DOE order. Nevertheless, PPPL participates in the operational framework of the national laboratory system, with security considerations similar to other non-classified facilities. PPPL is fully committed to the implementation of policies that ensure the protection of “official use only” information.

PPPL’s Export Control Officer is responsible for coordinating the Export Control Program. Export Control activities are addressed and reviewed through the relevant DOE orders and guidelines for control of Intellectual Property, including data obtained through industrial contracts such as Cooperative Research and Development Agreements and Work for Others, is reviewed for export control sensitivity and for patent disclosure considerations.

V.C.4. Budget, Finance, and Resource Management

The Business Operations Department provides institutional resource planning, budgeting, financial analysis, accounting operations, travel and temporary relocation services, procurement and subcontract administration services, and project planning and controls services to the Laboratory. The Business Operations Department is comprised of the following divisions: Accounting and Financial Controls; Budget Office; Procurement Division; Project Finance and Administration.

The Accounting and Financial Controls Division is principally responsible for providing general accounting functions for the Laboratory, including payroll, accounts payable, and maintenance of the general ledger. This division also provides the Laboratory with travel reservation and temporary relocation services.

The Budget Office is primarily responsible for providing the Laboratory with budget formulation and budget execution services, including the development and management of indirect pricing rates, and the maintenance of the Laboratory’s CAS Disclosure Statement. The Budget Office also provides pricing and contract administration support for the Laboratory’s work-for others program.

The Project Finance and Administration organization provides financial and administration support to the Laboratory’s portfolio of science programs. The Laboratory’s five Planning and Control Officers have a “dual” reporting responsibility, with the “solid line” being to the Head, Business Operations Office and the “dotted line” being to the senior level program manager whose programs they support. The dual reporting structure provides the Laboratory with the benefits of closely aligning these individuals with the program personnel that they support, while still maintaining some of the controllership benefits that are usually associated with more centralized financial organizations.

The Procurement Division buys the goods and services required by the Laboratory. The Division's objective is to procure these items in accordance with the requirements of the prime contract and applicable laws and regulations, at financial and contract terms most favorable to the Laboratory. Part of this responsibility includes the administration of the Laboratory’s procurement card system, which includes approximately fifty active cardholders placing transactions having an annual value of approximately $2.7 million.

Socioeconomic procurement goals have been negotiated with the DOE for FY02 covering procurement awards to small businesses, small disadvantaged businesses, women-owned small businesses, and hub zone small businesses. PPPL has achieved all of its socioeconomic performance goals for each of the past six years, and expects to achieve all of its socioeconomic goals for FY02. This consistent level of performance stems from a combination of unstinting outreach effort and careful pre-award evaluation of supplier capacity and capabilities. In recognition of its sustained record of success, the Laboratory received the Dwight D. Eisenhower Award for Excellence in Small Business Subcontracting from the United States Small Business Administration on June 10, 1999.

Princeton University and the DOE executed their second performance-based five year contract on October 19, 2001. This contract expires on September 30, 2006. PPPL has recently completed five years of operations under its previous performance-based contract. Under this contract, performance metrics were negotiated with the DOE, and PPPL tracked its performance against these metrics. Overall, the Laboratory’s performance against these metrics during this five year contract period ranged in the “excellent” to “outstanding” rating categories. PPPL performed self-assessments for key activities in the Laboratory operations area and conducted peer reviews of its various research programs. Laboratory staff worked closely with their DOE counterparts in developing their respective self-assessments. Both the self-assessments and the peer reviews have resulted in useful feedback that the Laboratory has acted or will act upon. We anticipate a similar level of successful performance during the FY02 through FY06 time period, pursuant to the terms of our current performance-based contract.

VI. Resource Projections

Table 1. PPPL Program Plan

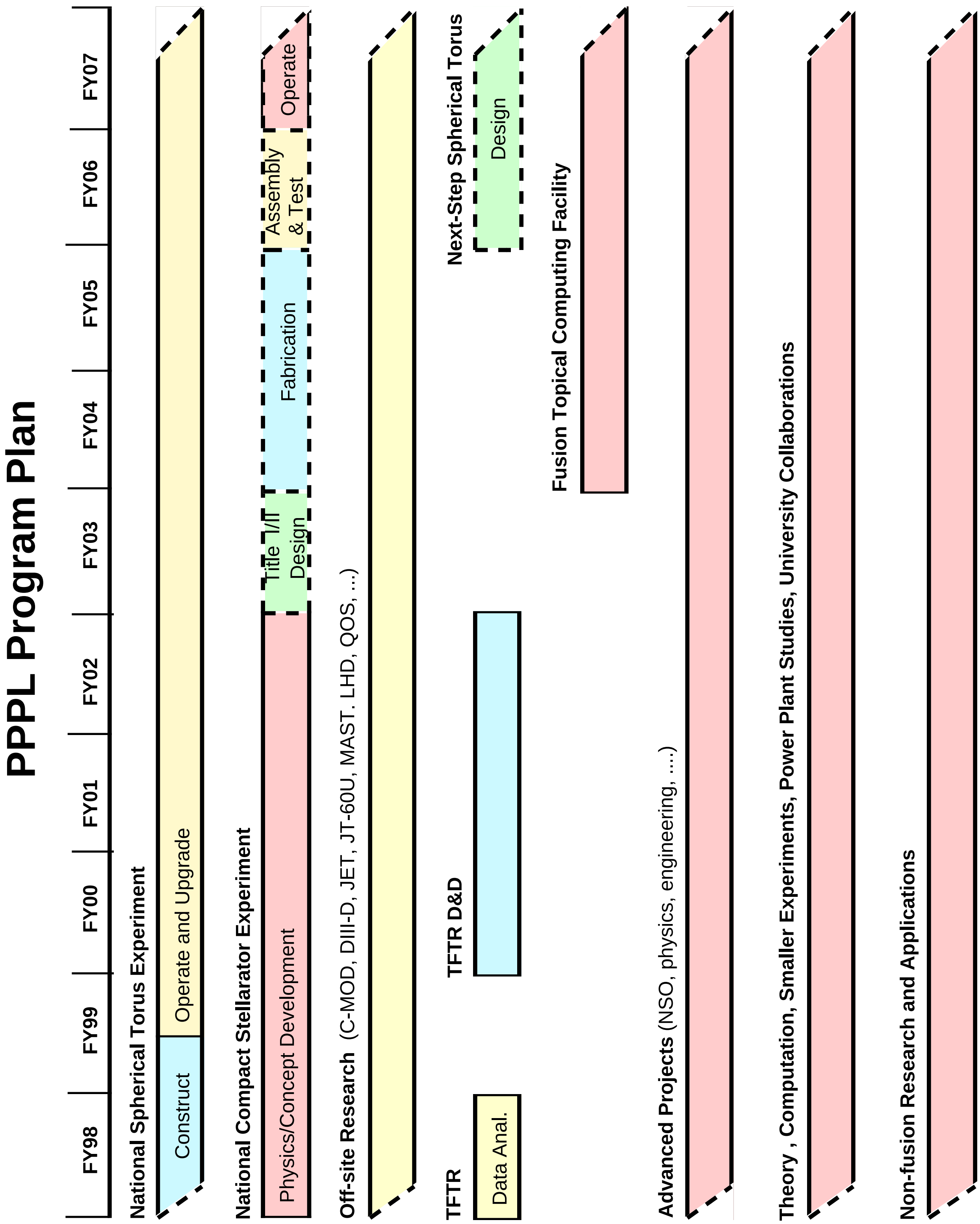


Table 2. Organization Chart

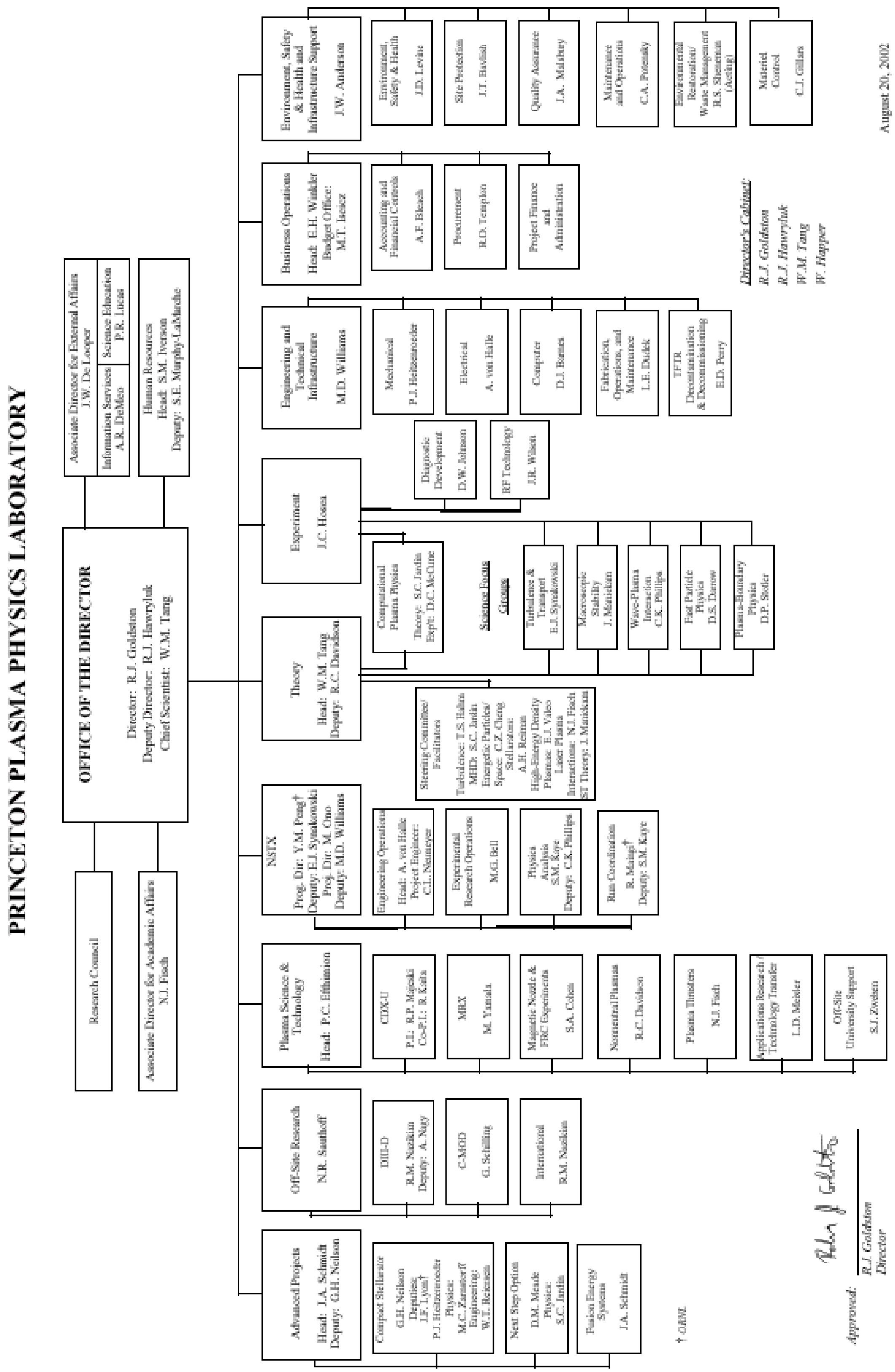


Table 3. Laboratory Funding Summary

Current Year Dollars ($M)

AT-Fusion Energy Sciences	**FY02**	**FY03**		**FY04**		**FY05**		**FY06**		**FY07**	
On-site Research	**Base**	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**
NSTX (PPPL)	22.8	26.5	1.4	26.5	3.6	28.6	3.6	29.8	3.6	31.0	3.6
NSTX Collaborators	*4.4*	*5.1*	*0.3*	*5.1*	*0.3*	*5.5*	*0.3*	*5.7*	*0.3*	*6.0*	*0.3*
ARIES	0.2	0.2		0.2		0.2		0.2		0.2	
NSO/Econ Studies/APEX	0.9	1.1	1.6	1.1	4.3	1.3	5.0	1.4	5.2	1.4	5.4
CDX-U	0.8	0.7	0.7	0.7	0.6	0.7	0.6	0.7	0.6	0.8	0.6
MRX	0.6	0.6	0.6	0.6	0.6	0.6		0.6		0.6	
Heavy Ion Fusion	1.1	1.1	1.4	1.1	2.1	1.2	2.1	1.2	2.2	1.3	2.3
Magnetic Nozzle (MNX)	0.2	0.2		0.2		0.2		0.2		0.2	
FRC Rot. Mg. Fields	0.1	0.2	0.5	0.2	0.5	0.2	0.5	0.2	0.6	0.2	0.6
Plasma Applications & Basic Phys.	0.8	0.7		0.7	0.4	0.8	0.5	0.8	0.5	0.9	0.5
Diagnostics (incl ECE/3D Imgng)	0.2	0.5		0.5		0.5		0.5		0.5	
Theory	3.7	3.9	1.1	3.9	1.2	4.6	0.8	4.8	0.8	5.0	0.9
CPPG & Adv. Scientific Comp.	2.0	2.1	0.2	2.1	0.2	2.2	0.5	2.3	0.5	2.4	0.5
FRC Theory	0.2	0.2		0.2		0.2		0.2		0.2	
Science Education	0.6	0.6	0.2	0.6	0.1	0.7		0.7		0.7	
Off-Site Research											
Off-Site Univ.	0.8	0.8	0.3	0.8	0.3	0.9	0.3	0.9	0.3	1.0	0.3
Off-Site Res. (US)	6.1	6.8	1.1	6.8	1.1	6.4		6.6		6.9	
Off-Site Res. (Int'l)	3.0	3.0	1.2	3.0	1.1	3.2	0.9	3.3	0.9	3.3	0.9
New Initiatives											
NCSX (PPPL) (1,2)	4.1	9.4	3.7	15.6	3.1	19.8	1.5	19.6	1.5	22.4	2.0
NCSX Collaborators	*1.3*	*2.6*	*0.5*	*1.6*	*0.7*	*2.3*	*0.7*	*3.0*	*0.7*	*3.8*	*1.0*
QPS (PPPL)	0.1	0.2	0.1	1.0	0.1	1.0	0.1	1.0	0.1	1.0	0.1
NSF Collaborations		0.3		0.3		0.3		0.3		0.3	
Topical Computing Center					3.0		5.0		7.0		7.0
NSST					2.0		4.0		5.0		20.0
PPPL ATFES Research Subtot	**48.6**	**58.9**	**13.9**	**65.9**	**24.5**	**73.5**	**25.4**	**75.4**	**28.8**	**80.2**	**44.7**
TFTR D&D/Facilities											
D-Site Caretaking	3.3	0.5		0.5		0.6		0.6		0.6	
TFTR D&D Removal	10.5										
TFTR D&D Pack., Trans & Dispsl	1.4										
Waste Management	3.2	2.7		2.7		2.8		2.8		2.9	
GPP	1.9	1.2	0.2	1.2	0.2	1.5		1.6		1.7	
Indirect Capital Equipment	0.4	0.1		0.1		0.1		0.1		0.1	
TFTR D&D/Facilities ***Subtotal***	***20.6***	***4.5***	***0.2***	***4.5***	***0.2***	***5.0***		***5.1***		***5.3***	
AT PPPL Fusion Energy Sciences	**69.2**	**63.4**	**14.1**	**70.4**	**24.7**	**78.5**	**25.4**	**80.5**	**28.8**	**85.5**	**44.7**
AT – PPPL + Exper. Collaborators	*74.9*	*71.1*	*14.9*	*77.1*	*23.7*	*86.3*	*23.5*	*89.2*	*28.9*	*95.3*	*32.1*
FS/GD- Safeguards & Security	**2.3**	**1.9**		**1.9**		**1.9**		**1.9**		**1.9**	
KJ - Adv. Sci. Comp. Research	**0.4**	**0.4**		**0.4**		**0.4**		**0.4**		**0.4**	
KA - High Energy Physics	**0.3**	**0.2**		**0.2**		**0.2**		**0.2**		**0.2**	
KH- Excess Facilities Disposition	**0.9**	**0.5**		**1.0**							
KX – Office of Science	**0.1**	**0.1**		**0.1**		**0.1**		**0.1**		**0.1**	
Non DOE Work for Others	2.2	1.5		1.5		1.5		1.5		1.5	
Non - AT Total	**6.2**	**4.6**		**5.1**		**4.1**		**4.1**		**4.1**	
PPPL Funding Total	**75.4**	**68.0**	**14.1**	**75.5**	**24.7**	**82.6**	**25.4**	**84.6**	**28.8**	**89.6**	**44.7**

1. Assumes Capital Equipment project.
2. CDR May 2002. Construction Start (CD#3) in April 2004

Table 4. Laboratory Personnel Summary

AT-Fusion Energy Sciences	FY02	FY03		FY04		FY05		FY06		FY07	
On-site Research	**Base**	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**
NSTX (PPPL)	107.8	111.2	4.6	108.2	12.9	113.5	16.2	114.9	15.7	116.0	15.2
ARIES	0.5	0.6		0.7		0.7		0.7		0.7	
NSO/Econ Studies/APEX	2.4	2.8	4.6	2.8	13.4	3.4	15.2	3.5	15.3	3.5	15.5
CDX-U	3.0	2.4	2.5	2.4	2.5	2.3	2.4	2.3	2.5	2.3	2.5
MRX	2.9	2.6	1.5	2.6	1.6	2.6		2.6		2.6	
Heavy Ion Fusion	5.2	3.3	4.0	3.1	4.0	3.3	3.9	3.3	3.9	3.4	4.0
Magnetic Nozzle (MNX)	1.2	1.2		1.2		1.2		1.2		1.2	
FRC Rot Mag. Fields	0.4	0.5	2.3	0.5	2.3	0.5	2.2	0.5	2.3	0.5	2.3
Plasma Applications & Basic Physics	4.7	4.1		4.1		4.3		4.3		4.3	
Diagnostics (incl ECE/3D Imgng)	1.1	1.4		1.4		1.4		1.4		1.4	
Theory	17.6	14.9	4.4	14.5	4.7	16.7	3.2	16.9	3.2	17.1	3.2
CPPG & Adv. Scientific Comp.	10.7	8.5	0.9	7.9	0.9	8.1	2.2	8.2	2.2	8.3	2.2
FRC Theory	1.2	0.6		0.6		0.6		0.6		0.6	
Science Education	2.6	2.2	0.2	2.2	0.1	2.5		2.6		2.6	
Off-Site Research											
Off-Site Univ.	2.2	2.3	0.7	2.3	0.7	2.4	0.7	2.4		2.4	
Off-Site Res. (US)	19.4	17.9	0.4	19.4	0.2	17.7	0.2	17.7	0.1	17.7	0.1
C-Mod LH Project	1.4	1.1	1.3	1.2	2.2						
Off-Site Res. (Int'l)	12.2	10.1	2.5	9.0	1.2	9.5	0.9	9.5	0.9	9.2	0.9
New Initiatives											
NCSX (PPPL) [1,2]	14.4	29.1	9.4	24.5	1.0	54.1		69.0	6.0	70.2	8.0
QPS (PPPL)	0.4	0.8	0.4	4.0	0.4	4.0	0.4	4.0	0.4	4.0	0.4
NSF Collaborations		1.2		1.2		1.2		1.1		1.1	
PPPL AT FES Research Subtotal	211.3	218.8	39.7	213.8	48.1	249.8	47.4	266.5	52.5	269.0	54.3
TFTR D&D/Facilities											
D-Site Caretaking	15.7	1.7		1.7		1.7		1.7		1.7	
TFTR D&D Removal	62.0										
TFTR D&D Pack., Trans & Dispsl	2.0										
Waste Management	15.1	12.3		12.3		12.3		12.3		12.3	
GPP	1.0	1.0		1.0		1.0		1.0		1.0	
TFTR D&D/Facilities **Subtotal**	*95.8*	*15.0*		*15.0*		*15.0*		*15.0*		*15.0*	
AT-PPPL Fusion Energy Sciences[3]	307.1	233.8	39.7	228.8	48.1	264.8	47.4	281.5	52.5	284.0	54.3
FSGD- Safeguards & Security	21.5	14.7	4.0	14.7	4.0	14.7		14.7		14.7	
KJ – Office of Comp. & Tech Res.	2.8	1.4		1.4		1.4		1.4		1.4	
KA - High Energy Physics	2.2	1.0		1.0		0.9		0.9		0.9	
KH-Excess Facilities Disposition	3.4	1.9		3.8							
KX –Office of Science											
Non DOE Work for Other	10.8	7.5		7.5		7.5		7.5		7.5	
Non – AT Total	40.7	26.5	4.0	28.4	4.0	24.5		24.5		24.5	
Indirect Technical Staff[4]	19.7	17.8		17.6		17.6		17.6		17.6	
Total Direct Personnel	367.4	278.1	43.7	274.8	52.1	306.9	47.4	323.6	52.5	326.1	54.3
Total Indirect Personnel (G&A)	162.4	156.4	4.0	156.4	4.0	158.4	4.0	159.4	4.0	159.4	4.0
Total FTE's	529.8	434.5	47.7	431.2	56.1	465.3	51.4	483.0	56.5	485.5	58.3
Less subcontract & term employees[5]	113.8	18.5		14.2		48.3		66.0		68.5	
Less Graduate students	29.0	29.0		30.0		30.0		30.0		30.0	
PPPL Staff	387.0	387.0		387.0		387.0		387.0		387.0	

1. Assumes Capital Equipment Project
2. CD#1 in CDR May 2002. Construction Start (CD#3) in April 2004
3. Includes direct allocations (cc54xx)
4. Technical Staff performing technical functions but charged indirectly (cc51, 52, 53, 54, 55xx)
5. Includes PPPL hired and supervised subcontractors

Table 5. Resources by Major Program (PPPL Funding by Secretarial Officer)

Current Year $M – BA	FY02	FY03	FY04	FY05	FY06	FY07
Office of Science						
Operating	62.9	50.0	52.4	59.2	61.0	73.3
Capital Equipment	4.4	12.2	16.8	17.8	17.9	10.5
General Plant Projects (GPP)	1.9	1.2	1.2	1.5	1.6	1.7
Total	**69.2**	**63.4**	**70.4**	**78.5**	**80.5**	**85.5**
FS/GD – Safeguards & Security	1.8	1.9	1.9	1.9	1.9	1.9
KJ – Adv. Sci. Comp. Research	0.4	0.4	0.4	0.4	0.4	0.4
KH – Excess Facilities Disposition	0.9	0.5	1.0			
High Energy Physics	0.3	0.2	0.2	0.2	0.2	0.2
KX – Office of Science	0.1	0.1	0.1	0.1	0.1	0.1
Non DOE Work for Others	2.2	1.5	1.5	1.5	1.5	1.5
Total Laboratory Funding (w/o collaborator funding)	**75.4**	**68.0**	**75.5**	**82.6**	**84.6**	**89.6**

Table 6. Collaborator Funding for National Projects

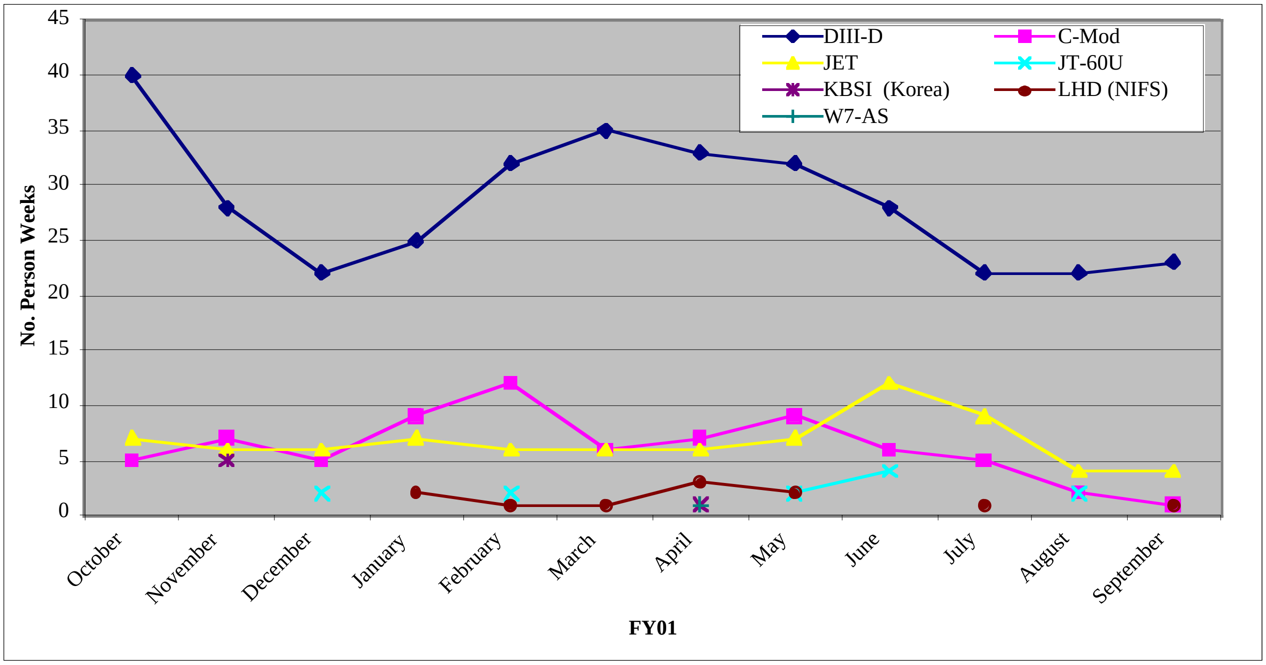
AT-Fusion Energy Sciences	FY02	FY03	FY04	FY05	FY06	FY07
NSTX	4.4	5.1	5.1	5.5	5.7	6.0
NCSX	1.3	2.6	1.6	2.3	3.0	3.8
Total	**5.7**	**7.7**	**6.7**	**7.8**	**8.7**	**9.8**

Table 7. Laboratory Staff Composition

	Ph.D.		MS/MA		BS/BA		Other		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Professional Scientist	93	19.2	0	0	0	0	2	0.4	95	19.5
Professional Engineer	14	2.9	31	6.4	33	6.8	5	1.0	83	17.1
Management & Administrative	3	0.6	21	4.3	23	4.8	28	5.8	75	15.4
Support/ Technician	0	0	0	0	13	2.7	199	41.1	212	43.6
All Other	0	0	0	0	1	0.2	20	4.1	21	4.3
Totals	110	22.6	52	10.7	70	14.4	252	52.3	486	100

(April 2002)

Table 8. Experimenters at Designated User Facilities FY01



Time Spent Collaborating at Other Facilities

Table 9. Laboratory Space Distribution

Location	Area (Gross Sq. Ft.)
Main Site	724,366
Off Site	700
TOTAL	725,066

Table 10. Facilities Replacement Value

Facilities Type	Replacement Value (FY02 Dollars)
Buildings	211,548,180
Roads and Pavements	4,045,868
Utilities	46,081,162
All other	131,009,474
Total	392,684,684

Table 11. Major Construction Projects

General Plant Projects Funding ($ Thousands)(BA)

Projects	FY02	FY03	FY03-05
Safety	0	500	3,000
Improvement	1,370	500	3,800
Environment	0	200	1,000
TOTAL	1,900	1,200	7,800

Table 12. Equal Employment Opportunity

	Officials/ Managers	Scientists & Engineers	Technicians	All Other	Total	
	No.	No.	No.	No.	No.	%
Minority						
Males	1	33	18	5	57	14.0
Females	1	2	1	15	19	24.3
White						
Males	52	97	159	41	349	85.9
Females	5	6	2	46	59	75.6
Black						
Males	0	2	16	4	22	5.4
Females	1	0	1	12	14	17.9
Hispanic						
Males	0	0	0	1	1	0.2
Females	0	1	0	2	3	3.8
Native American						
Males	0	0	2	0	2	0.4
Females	0	0	0	0	0	0
Asian/Pacific Islander						
Males	1	31	0	0	32	7.8
Females	0	1	0	1	2	2.5
Total						
Males	53	130	177	46	406	84.3
Females	6	8	3	61	78	15.7

(April 2002)

Table 13. Completed Dissertations for 2001 – 2002

Sechekochinin, Alexander, "Statistical Theory of Small-Scale Turbulent Astrophysical Dynamos," January 2001, Advisor: Russel Kulsrud.

Strasburg, Sean, "Dynamics of Intense Charged Particle Beams," January 2001, Advisor: Ron Davidson.

Breslau, Joshua, "Numerical Study of Magnetic Reconnection in Merging Flux Tubes," April 2001, Advisor: Steve Jardin.

Li, Xiaho, "Laser-Plasma Interaction in Plasma Channel and Relativistic Particle Dynamics," April 2001, Advisor: Gennady Shvets.

Carter, Troy, "Experimental Studies of Fluctuations in a Reconnecting Sheet," August 2001, Advisors: Massaki Yamada, Russel Kulsrud, and Hanto Ji.

Ping, Yuan, "Soft X-Ray Lasers and Raman Amplification in Plasmas, May 2002, Advisor: Szymon Suckewer.

(listing as of 5/21/02)

Figure 1. Condition of Laboratory Space

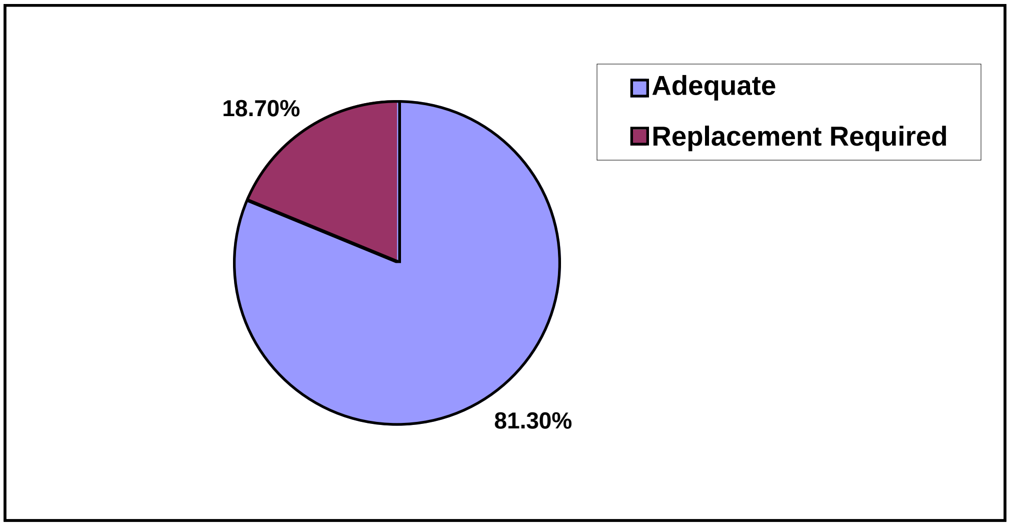


Figure 2. Use and Condition of Laboratory Space

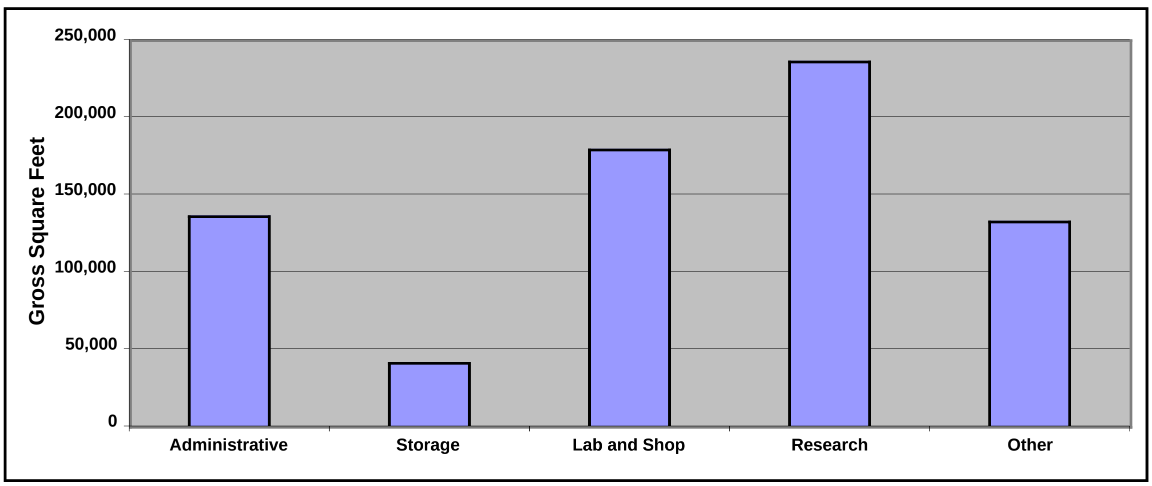
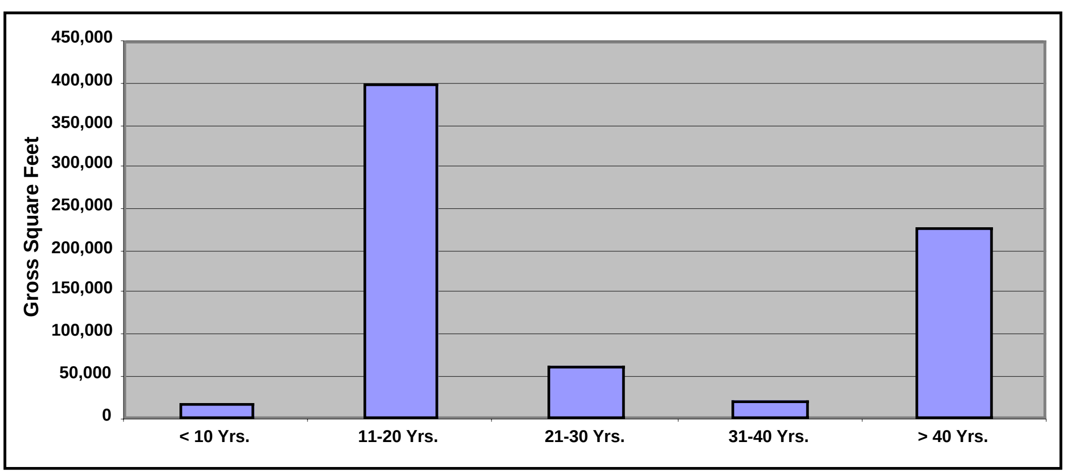


Figure 3. Age of Laboratory Buildings



Acronyms

ALPS	Advanced Liquid Plasma-facing Surface
AMTEX	American Textile
ARIES	Advanced Reactor Innovation Evaluation Study
BES	Basic Energy Sciences
CAMP	Capital Asset Management Process
CCWP	Central Chilled Water Plant
CDX-U	Current Drive Experiment-Upgrade
C-Mod	Alcator C-Mod - experimental fusion device in Massachusetts
CPPG	Computational Plasma Physics Group
CRADA	Cooperative Research and Development Agreement
CY	Calendar Year
D&D	Decontamination and Decommissioning
DIII-D	Doublet three - experimental fusion device in California
DOE	Department of Energy
EBW	Electron Bernstein Wave
ECH	Electron Cyclotron Heating
EEO	Equal Employment Opportunity
ES&H	Environment, Safety and Health
ES&H/IS	Environment, Safety and Health and Infrastructure Support Department
ET	Experiment at University of California
FESAC	Fusion Energy Sciences Advisory Committee
FIRE	Fusion Ignition Research Experiment
FLC	Federal Laboratory Consortium
FRC	Field Reversed Configuration
FY	Fiscal Year
GA	General Atomics
GPP	General Plant Projects
HBT-EP	Experiment at Columbia
HHFW	High Harmonic Fast Wave
HIT-II	Experiment at University of Washington
HSX	Experiment at University of Wisconsin
HVAC	Heating, ventilating and air conditioning
ICRF	ion cyclotron for radio frequencies
ITER	International Thermonuclear Experimental Reactor
JAERI	Japan Atomic Energy Research Institute
JET	Joint European Torus (Experimental fusion facility in England)
JT-60U	Experimental fusion facility in Japan
kA	Kilo-amps
KSTAR	Korea Superconducting Tokamak Research Project
kW	Kilo-watts
LHD	Large Helical Device
LANL	Los Alamos National Laboratory
LLNL	Lawrence Livermore National Laboratory
LPDA	Laboratory Program Development Activities
MAST	Experiment at Culham, England
MFE	Magnetic Fusion Energy
MHD	Magnetohydrodynamics
MIT	Massachusetts Institute of Technology
MNX	Magnetic Nozzle Experiment
MRX	Magnetic Reconnection Experiment
MSE	Motional Stark Effect
MST	Experiment at University of Wisconsin
NASA	National Aeronautics and Space Administration
NBI	Neutral Beam Injection

NCSX	National Compact Stellarator Experiment
NERSC	National Energy Research Scientific Computing
NSF	National Science Foundation
NSTX	National Spherical Torus Experiment
OFES	Office of Fusion Energy Sciences (DOE)
ORNL	Oak Ridge National Laboratory
PAC	Program Advisory Committee
PBX-M	Princeton Beta Experiment-Modification
PPPL	Princeton Plasma Physics Laboratory
PSACI	Plasma Science Advanced Computing Initiative
QA	Quasi-axisymmetry
QO	Quasi-omniginous
QOS	Quasi-omniginous Stellarator
R&D	Research and development
RF	Radio-frequency
RFP	Reverse Field Pinch
RMF	Rotating Magnetic Field
SC	Office of Science (DOE)
SCT	Experiment at University of California
SDAC	Scientific Discovery through Advanced Computing
SOL	Scrape of layer
SPF	Strategic Facility Plan
ST	Spherical torus
START	ST in Culham England (Small Tight Aspect Ratio Tokamak)
STTC	Experiment at University of Washington
STX	Experiment at University of California
T	Tesla (a unit of magnetic strength)
TFTR	Tokamak Fusion Test Reactor
TS-3	Spheromak Experiment at University of Tokyo
UCSD	University of California-San Diego
U.K.	United Kingdom
US	United States
WFO	Work-for-Others