PRINCETON PLASMA PHYSICS LABORATORY

A Department of Energy National Laboratory

Institutional Plan

FY 2004 – FY 2008

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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 goal is consistent with the National Energy Policy issued in May 2001. 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. 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). 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.

This is a time of new and exciting opportunities. The United States has announced a return to the ITER project which will allow PPPL and the US fusion community to participate in a burning plasma experiment.

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 operated by PPPL as a national facility with collaborators from universities, industry, and National Laboratories. International collaboration is also an important research component on NSTX. 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 35% 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 is now available due to the successful completion of the decommissioning and decontamination of the Tokamak Fusion Test Reactor (TFTR) in 2002. Based on the encouraging NSTX research progress so far and the comprehensive 5-year plan, it is envisioned that the NSTX can supply the physics base needed for the physics validation of NSST as early as 2007. 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 recommended by FESAC in March 2003.

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 and fabricated by the Laboratory in partnership with the Oak Ridge National Laboratory. 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 Fusion Energy Sciences Advisory Committee said that its potential 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 NCSX fabrication project was approved (Critical Decision 1) in 2002 with an Acquisition Execution Plan calling for major equipment fabrication from 2003 to 2007 at a cost of $73.5M. Title II design and manufacturing development activities began in FY03. The manufacture of the major stellarator device components will be carried out in FY04 and FY05. The major machine subassemblies will be built starting in FY05 and the final machine assembly in the NCSX test cell will begin in FY06. Preparation of the facility and ancillary systems will proceed in parallel with the device fabrication activities. An integrated system test program will be carried out in FY07, leading to achievement of the First Plasma milestone in June 2007, whereupon the NCSX project will be completed and operations will commence.

Research preparations for NCSX will proceed in parallel with the fabrication project. It will start at a relatively modest level in FY04 and FY05 and ramp up in FY06 and FY07 to support research hardware preparation and staff buildup for the experimental program. The experimental program will progress through initial phases in FY07 and FY08, along with continued buildup of machine capabilities and staff.

The Laboratory has a leadership role in nurturing the national innovative confinement configuration process and participates in organizing 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.

Off-Site Research

As a key approach to achieving PPPL's objective of addressing important scientific questions using the most appropriate facilities worldwide, members of the PPPL research staff participate in experiments at leading national and international facilities, contributing important skills to the host teams as part of integrated multi-institutional teams. 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; in essence, the PPPL participants in off-site research are bringing the PPPL institution's capabilities to contribute to the research programs at the remote sites. This provides an excellent platform to address a wide range of key issues of fusion plasma science. A key interest of PPPL collaborations includes integration of 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), C-Mod (located at the Massachusetts Institute of Technology), and international programs, and are key performers for the design and construction of upgrades and modifications to these devices.

Since PPPL recognizes the scientific productivity of the out-bound collaborative scientific teams, PPPL expects to maintain a collaborative program at a substantial level even with a second proof-of-principle device (NCSX) on-site. 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 NCSX and continues to strengthen national collaboration on NSTX.

Theory and Computation

The continuing impressive advances in computational power have greatly expanded the capabilities for studying all areas of plasma science. PPPL is well coupled to such progress and has enhanced its 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, Theory and Computation contributes strongly to innovation in plasma confinement concepts, such as the spherical torus, the stellarator, feedback stabilization of tokamaks the stability of the Field Reversed Configuration, and exploration of burning plasma physics issues of prime interest to future devices such as ITER. The 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 establishing the Plasma Science Advanced Computing Institute (PSACI), which was stimulated by the need 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.

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 astrophysics, and plays an important role in the training of graduate students and postdoctoral associates. The Laboratory also encourages technology transfer from fusion research and technology 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.

Burning Plasma Experiments

Over the past 2 years, the US fusion community has affirmed both the scientific value of the study of burning plasmas and the scientific and technological readiness to proceed. The US government has taken steps to implement a burning plasma program. PPPL seeks to play a key role in both the associated construction and supporting research.

Following a series of university-initiated workshops on burning plasma science, the 2002 Snowmass Fusion Summer Study refined key scientific questions related to burning plasmas and then performed a uniform technical assessment of the capabilities of IGNITOR, FIRE, and ITER to address those questions. These community conclusions provided the technical basis for the FESAC's preparation of its recommendations on the US burning plasma strategy, which concluded that now is the time to start the burning plasma program and recommended a dual-path burning plasma strategy involving both ITER and FIRE in the near term and either joining ITER as a construction partner if terms acceptable to the US can be agreed by the parties or proceeding with FIRE.

PPPL, with its experience in large-scale tokamak research and integrated research capability, seeks to play a significant role in the US burning plasma program. PPPL will work with the community in the establishment of a US Burning Plasma Program. In ITER, PPPL offers to serve as the host institution for US ITER activity and also to work with the community on integrating the US burning plasma program with the worldwide ITER program; the ITER program is planned to pursue both burning plasma physics for durations approaching steady state and technologies relevant to a magnetic fusion reactor. In FIRE, PPPL leads the current design study aimed at providing a lower-cost approach to the study of the physics of burning plasmas, with particular emphasis on the study of high-power-density burning plasmas in advanced tokamak configurations for several current redistribution times.

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 210 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 provides 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 and Roles

II.A. Mission

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.

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 mission of the US Fusion Energy Sciences Program is to advance plasma science, fusion science, and fusion technology — the knowledge base needed for an economically and environmentally attractive fusion energy source.

III.A. PPPL Vision and Strategic Goals

The PPPL Collaborative Vision:
Deepening the understanding of plasmas and creating key innovations to make fusion power a practical reality.

The national fusion mission is deeply consonant with the mission, vision 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 fusion energy.

The programs and activities listed below constitute the strategic approach PPPL has chosen to contribute to mission for the Fusion Energy Sciences Program. The program is 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. 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 based on solid scientific understanding to advance fusion and plasma science.

III.C. National Spherical Torus Experiment

PPPL is responsible for the operation and management of the NSTX facility. NSTX research is being carried out by the National Research Team and is directed towards the investigation of key plasma characteristics relevant to the regimes of order-unity beta in the ST field line topology and the establishment of the required underlying physics understanding in achieving these regimes. As NSTX research strives to develop high performance operating scenarios, advanced diagnostics and control tools will be implemented to gain access to these regimes and to enable the research. The NSTX experimental platform will produce a broad physics base from which to define the next development stages in ST fusion energy science R&D, such as the Performance Extension stage with 5-10 MA plasma current. Importantly, as these regimes challenge theory with respect to high beta, large plasma flows velocities, and field line topology, they serve as powerful test beds for physics issues of broad importance to tokamaks, other confinement systems with overdense plasmas, and high beta plasmas found in astrophysical settings.

Two major research thrusts will be pursued from 2004 through 2006. These are the achievement of high beta, high confinement, high bootstrap fraction plasma conditions relevant to an ST fusion power plant, and the development of solenoid-free operations at plasma parameters relevant to a Component Test Facility (CTF). In 2007 - 2008, these elements will be combined as the highest level of integrated high performance, non-inductive sustained operations are pursued. The achievement of particular performance and integration targets in these thrusts will be grounded in an understanding of the topical science areas of MHD stability, transport, wave-particle interactions, boundary physics, and solenoid-free plasma current generation and sustainment.

High beta, high confinement, and high bootstrap fraction plasmas relevant to an advanced ST power plant. A major goal is improving the plasma performance as measured by simultaneously advancing the plasma toroidal beta, normalized beta, confinement time, and pulse length. An overarching goal for the FY04-08 period is to realize discharges approaching 40% toroidal beta, operating near the wall-stabilized limits using active feedback control, non-inductively sustained for pulse durations much greater than the current relaxation times. These plasmas will benefit from strong shaping, flexible heating and current drive tools, advanced particle control tools, and techniques that will conserve the inductive flux that will be developed in the second major thrust. An intermediate goal for the 2006 time scale is to establish the individual plasma scenarios and enabling tools required by the integrated high performance long pulse plasmas on NSTX. These scenarios include the demonstration of high β_T and high confinement for longer than an energy confinement time over as wide a range of toroidal field and current as possible. For the purposes of developing MHD mode control strategies, a parallel goal is the development of high β_N plasmas approaching the with-wall limit for time periods longer than several energy confinement times.

Solenoid-free operations at plasma parameters relevant to CTF. A major goal is developing the capability to initiate and sustain plasmas without the aid of solenoid-induced flux. In the 2006 time scale, a goal is the development of plasmas with non-inductive sustained operations for pulse lengths greater than a current relaxation time at toroidal beta values comparable to those required for CTF without requiring active mode control. Also, in separate plasmas, NSTX aims to demonstrate solenoid-free startup approaches. This will be achieved through the study of a combination of techniques, including coaxial helicity injection, poloidal field coil induction, bootstrap current, and additional current drive through the application of High Harmonic Fast Waves (HHFW) delivering 6 MW power, neutral beam injection delivering 7 MW power, and Electron Bernstein Waves (EBW) proposed to deliver up to 3 MW power.

The achievement of these goals will represent major advances in determining the scientific and technical attractiveness of the spherical torus. The high level goal of establishing an extrapolable basis for moving forward demands that their achievement be grounded in a detailed understanding of the physics of high beta plasmas in the strong toroidicity of the ST configuration. To enable this, the two thrusts described above are supported by topical research indicated in Table 15. Achieving the results outlined above and enabling these developments through plasma science will characterize the NSTX Proof-of-Principle experiment.

Several facility upgrades have been proposed in order to meet the research goals. These include a system for active MHD resistive wall mode (RWM) control to enable operations near the with-wall limit, poloidal field coil modifications for enhanced shaping and control to maximize that limit, Electron Bernstein Wave (EBW) heating for localized, off-axis current drive, and particle pumping for density control. These will increase the flexibility and range of plasma operation on NSTX, important for scientific investigations as well as meeting the performance goals outlined above, and the research for three of these (EBW, edge control through the application of lithium, and RWM control) will have implications for both the NSTX program and also for research far beyond NSTX. The impact of the EBW and lithium power and heat flux control research is described below.

An EBW heating and current drive system will take maximal advantage of the unique ST magnetic field line geometry and will provide valuable information for electron heating and current drive systems for other over-dense plasma confinement configurations such as the Reversed Field Pinch and the Spheromak. Modeling of the long pulse, high beta goal outlined above reveals that EBW can play a critical role in providing off-axis current drive, important for keeping the core q values elevated for high beta and bootstrap current fractions. Building on the ECCD successes on ASDEX-U and DIII-D, its localized deposition is predicted to be of value for stabilizing neoclassical tearing modes in these plasmas. It will also be of value in solenoid-free plasma startup studies by its ability to create initial toroidal current with high electron temperatures. EBW gyrotrons delivering up to 3 MW power is proposed to be available for research during FY06-08.

Particle fueling and recycling control is also a key element of the research plan for the FY04-08 period, as reduced density is required for increased efficiency of all forms of current drive. The research plan calls for the investigation of the promise of using lithium as a plasma facing surface for particle pumping, in the form of lithium pellets, lithium coating deposited through evaporation on plasma facing components, and then as a liquid lithium divertor. Data obtained in the first two stages, in close collaboration with the National Virtual Laboratory of Technology and experiments on CDX-U, should provide enough information by the end of 2006 to develop and install a liquid lithium divertor module for use in 2009. The successful development of such lithium technologies could have profound implications not only for NSTX, but also for toroidal confinement systems in general, as a solution for particle and heat flux control in future high performance fusion power systems.

To support the exciting scientific research program on NSTX, a broad suite of sophisticated profile diagnostic upgrades are being proposed by both PPPL and collaborating institutions. Major proposed diagnostic enhancements include MSE/LIF (Motional Stark Effect/Laser Induced Fluorescence) 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 (Charge Exchange Recombination Spectroscopy) to measure the plasma poloidal flows to complement the existing toroidal CHERS system.

The NSTX National Research Program is expected to contribute not only to the understanding of fusion relevant ST plasmas of very high beta and toroidicity in particular, but also toroidal fusion plasmas in general and naturally occurring plasma phenomena in space. These contributions include:

- Solenoid-free plasma formation via Coaxial Helicity Injection and Electron Bernstein Wave (EBW), taking advantage of the small magnetic flux content in the compact Innovative Confinement Concepts (ICCs) including the RFP, the Spheromak, the Field Reversed Configuration (FRC), and the ST. The physics mechanisms of startup (field line reconnection and large plasma flow) are similar in nature to the physics responsible for the formation of solar flares.
- Heating and current drive via High Harmonic Fast Wave (HHFW), Electron Bernstein Wave (EBW), and Neutral Beam Injection (NBI), taking into account the strong local magnetic shear, very high dielectric constant (over-dense plasmas), and supra-Alfvén energetic ions. This parameter regime is shared among these ICCs and also characterizes much of the ionospheric and stellar plasmas, and their interactions with electromagnetic waves and energetic particles.
- Very high stability and operational beta limits, taking advantage of naturally large stable elongations, strongly stabilizing magnetic field line structure, comparable Alfvén and sound speed, minimal external plasma inductance, the potential for large fully aligned bootstrap current, and rigidity of inboard 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 high temperature collisionless toroidal plasmas. As the aspect ratio approaches the lower limit of unity, the spherical torus also approaches the physics regimes of FRC and Spheromak, likely extending their existing database from modest temperatures to high-temperature collisionless plasmas.
- Reduced micro-turbulence and enhanced transport barriers, taking advantage of the reversal of particle precession at high beta, the very large sheared flow at high beta and strong momentum input such as via the NBI, 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 stabilize the larger scale electrostatic turbulence that has so far dominated the low-beta toroidal plasmas and reveal an increased role for small size scale electromagnetic turbulence. New understanding of electromagnetic turbulence in the ST will also contribute directly to the progress of research in all other toroidal configurations, as well as 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 new scientific opportunities to boundary physics research towards effective dispersal of large heat fluxes in future high performance fusion 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 nearly monotonic q profiles. New prospects for beneficial synergy among these physics features in integrated operation scenarios are therefore introduced by the ST, and engender the thrusts articulated in the NSTX research plan for

FY04-08. Success in the planned research would establish a new and attractive scientific basis for fusion energy and its development.

A collaborative national research 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. 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 Program and Project.

III.D. National Compact Stellarator Experiment

A new experimental facility, the National Compact Stellarator Experiment (NCSX), was approved in 2001. It will commence operations during this Institutional Plan time span. The NCSX, which will be sited at the Laboratory, is the centerpiece of a national 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. The project is led by PPPL in partnership with the Oak Ridge National Laboratory (ORNL), with other institutions collaborating. The DOE-approved Acquisition Execution Plan calls for major equipment fabrication from 2003 to 2007 at a cost of $73.5M. The project began in 2003 and at this time is proceeding with Title□ design and manufacturing development activities. Component fabrication activities will start in FY04, subassembly operations will start in FY05, and final machine assembly will start in FY06. Preparation of the facility and ancillary systems will proceed in parallel with the device fabrication. The project will be completed in June 2007 with the achievement of the First Plasma milestone, whereupon NCSX operations will commence.

Compact Stellarators

The attraction of compact stellarators is their promise of providing a compact (aspect ratio less than or equal to 4.4) high-beta (greater than or equal to 4%) plasma that does not disrupt and can be steady-state without external current drive or feedback control systems. The benefits derive from the three-dimensional nature of stellarators, which enables them to produce a rotational transform and nested magnetic surfaces with external coils alone and to obtain prescribed physics properties through three-dimensional plasma shaping. The physics origins of compact stellarators are in theoretical work 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 a magnetic coordinate system known as Boozer coordinates. These quasi-symmetric stellarator configurations have drift orbits similar to equivalent symmetric configurations such as tokamaks or spherical tori, and thus similar neoclassical transport. Rotation in the quasi-symmetric direction has low damping, as in a symmetric configuration, allowing efficient flow-shear control of turbulence. The physics similarities of quasi-symmetric stellarators to tokamaks allows them to make use of tokamak scientific and technical advances. Successful experimental tests of quasi-symmetry are now being carried out in the Helically Symmetric Experiment at the University of Wisconsin.

Mission and Design

The NCSX will test the quasi-axisymmetric stellarator (QAS) concept, in which the symmetry direction is toroidal, like that of a tokamak. 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 building on both tokamak and stellarator physics advances. The mission in detail, is to:

- Demonstrate conditions for high-beta disruption-free operation, compatible with bootstrap current and external transform in a compact stellarator configuration.
- Understand beta limits and limiting mechanisms in a low-aspect-ratio current-carrying stellarator.
- Understand reduction of neoclassical transport by quasi-axisymmetric (QA) design.
- Understand confinement scaling and reduction of anomalous transport by flow-shear control.
- Understand equilibrium islands and stabilization of neoclassical tearing-modes by choice of magnetic shear.
- Understand compatibility between power and particle exhaust methods and good core performance in a compact stellarator.

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.

The NCSX has been designed around an optimized QAS configuration with attractive plasma physics properties and ample experimental flexibility. It has three periods, an aspect ratio $R/\langle a \rangle = 4.4$, and strong axisymmetric and three-dimensional shape components. 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 magnetic fields are produced by a system of eighteen modular coils of three different shapes, along with poloidal field, toroidal field, and external trim coils. A conformal vacuum vessel provides a clean environment for the plasma and provides access for heating and diagnostics.

The physically relevant measure that is used to judge the adequacy of quasi-symmetry is the effective helical magnetic ripple parameter which is directly related to the neoclassical transport in the $1/\nu$ regime where power plants will operate. In the NCSX design the ripple parameter is only 1.5% at the plasma edge and an order of magnitude less in the core. This results in negligible calculated thermal transport losses due to the residual ripple. Other optimization goals that were achieved in the design of NCSX: stability to kink, ballooning, neoclassical tearing, vertical, and Mercier modes at beta=4%; a rotational transform profile that increases from the center to the edge; and good magnetic surfaces at an aspect ratio of 4.4. Moreover, these optimization goals are achieved consistent with engineering constraints to ensure feasibility of fabrication. Flexibility studies have shown that fully stable beta>6% free-boundary equilibria are accessible with slightly higher effective ripple using the NCSX coils. The coils provide flexibility to vary the beta limits and test the physics effects of varying the internal and external rotational transform, the shear, and the helical ripple.

The NCSX will have a major radius of 1.4 m and a magnetic field 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. The NCSX will be 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.

The NCSX design is supported by theoretical analyses, experimental results, and a sound engineering concept. The NCSX design methodology and the resulting design have been favorably reviewed in an extensive series of peer reviews over the past few years.

Project History

In 2001, the project passed a Department of Energy Physics Validation Review, was designated a proof-of-principle experiment by FESAC, and received approval of Critical Decision 0, Mission Need, from the Department's Office of Fusion Energy Sciences. A successful DOE-SC "Lehman" conceptual design review of physics, design, cost and schedule, ES&H, and management took place in May 2002. The NCSX fabrication project was approved (Critical Decision 1) in 2002 with an Acquisition Execution Plan calling for major equipment fabrication from FY03 to FY07 at a cost of $73.5M. Title I design and manufacturing development activities began in FY03.

Plans: NCSX Major Item of Equipment Project

The following are major milestones for the NSCX project:

FY03
- Title I design of the coils, vacuum vessel, and other major components.
- Manufacturing development/prototyping-modular coil winding forms, vacuum vessel.
- Testing of legacy vacuum pumping, neutral beam, and electrical equipment items.
- Updating of cost and schedule estimates for all subsystems.

FY04
- PPPL Preliminary Design Review, October, 2003.
- DOE Performance Baseline Review, November, 2003
- Critical Decision 2, Approval of Performance Baseline, November, 2003
- Winding of a full-scale prototype modular coil.
- Critical Decision 3, Approval for Fabrication.
- Final Design Reviews and award of fabrication contracts for vacuum vessel and coils.

FY05
- Receive first vacuum vessel period.
- Receive TF and PF coils.
- Install D-site to C-site power supply cables.
- Begin neutral beam refurbishment.
- Begin facility modifications.

FY06
- Assemble field periods.
- Begin final machine assembly.

FY07
- Complete final machine assembly.
- Complete facility modifications and installation of ancillary equipment for 1st Plasma.
- Complete Integrated Systems Test Program
- Critical Decision 4, Approval for Operation.
- Achieve First Plasma Milestone.

Plans: NCSX Research

Research preparations for NCSX will proceed at a relatively modest level through FY05, while operation is still a few years away. Starting in FY05, open community discussions will begin to prepare the project and potential collaborators for broad participation in NCSX research. In FY06-FY07, research activities will be augmented with a hardware development component. The experimental program on NCSX will begin in FY07 and progress through several phases by the end of FY08.

FY03-FY05

The focus will be on keeping abreast of stellarator physics developments, factoring those developments into the planning of the NCSX experimental program, and preparing long-lead-time physics analysis tools for NCSX application:

- Upgrade diagnostic concept development. The NCSX team will establish requirements for diagnostic upgrades to be added in the OH and initial NBI heating phases. A key aspect of this is establishing interfaces with the vacuum vessel and coils to ensure compatibility with the final designs of those components. Diagnostic design studies will be undertaken in preparation for engineering design and fabrication work.
- The first NCSX research forum will be held to invite and encourage participation by the US community in the research and diagnostic preparations for NCSX. The forum will help prepare the project and the community for hardware development activities to be funded starting in FY06.
- Research and development of boundary control strategy. The NCSX team will adapt and apply analytical tools (e.g., PIES, MFBE, DEGAS) and incorporate experimental results from foreign stellarator divertor experiments to set requirements for the design of power and particle handling upgrades (plasma-facing components, edge diagnostics) in preparation for NCSX boundary physics research. The plasma-facing components will be implemented in a phased manner, ultimately leading to a pumped divertor.

- Development of plasma control strategies for a range of NCSX operating scenarios. The NCSX team will adapt tools that are available (e.g., STELLOPT, TRANSP, PIES) or being developed (e.g., V3FIT) to establish requirements and physics designs for magnetic diagnostic upgrades, control algorithms, and trim coils; and to develop data analysis capabilities.
- Support comparison of calculations from Theory-developed MHD equilibrium and stability codes with experimental results from international stellarators, in preparation for the operation of NCSX. The NCSX team will collaborate with the Theory program and the German and Japanese stellarator programs in understanding linear and non-linear global stability implications for NCSX. The NCSX contribution will be to expedite the theory-experiment comparisons by participating in the selection and analysis of experimental data sets and in the specification of code runs.

FY06-FY07

Research preparation activities begun in earlier years will continue. In addition, the effort will be augmented with a hardware development component to prepare equipment upgrades that need to be ready for installation during the first two years of operation (internal trim coils, external trim coil power supplies, plasma-facing components, 350°C bakeout, upgrade diagnostics, control system).

FY07-FY08

The experimental program on NCSX will begin in FY07. The program will progress through the initial phases of the program. This will also be a period of buildup of machine capabilities and research staff as the program requirements expand.

- Initial Operation. A short campaign will be carried out to exercise the coils and power supplies and demonstrate the capability to create a plasma in the device. This phase will be primarily for system shakeout.
- Flux Surface Mapping. Magnetic flux surfaces will be mapped out using an electron beam apparatus for a range of magnetic configurations, both with cold and room-temperature coils. The rotational transform and quasi-axisymmetry will be verified. External trim coil power supplies will be added.
- Initial Ohmic Operation. Ohmically heated plasmas will be used to develop plasma control capabilities and commission diagnostics. Some physics studies can be carried out, such as investigations of vertical stability, density limits, global confinement scaling, and profile characteristics. Internal trim coils, several diagnostics, and control systems will be added.
- Initial Auxiliary Heating. Neutral beams will be commissioned and tested, carbon plasma-facing components will be installed, 350°C bakeout capability will be implemented, and control systems will be enhanced in preparation for operation with auxiliary heating. Experiments with auxiliary heating will start at the end of FY-2008.

Plans: Collaboration in the QPS Project

The Laboratory is a collaborator in the Quasi-Poloidal Stellarator (QPS) experiment, a concept-exploration-scale stellarator experiment being built at the ORNL. The role of QPS in the national stellarator proof-of-principle program is to push stellarator physics to aspect ratios less than 3 and test an optimized quasi-poloidal stellarator configuration. The QPS project has a close relationship with the PPPL-led NCSX project which, though a separate activity, involves the same two institutions and many of the same people. Coordination between the two projects facilitates efficient development and sharing of tools and knowledge, to the overall benefit of the fusion program.

In FY04 PPPL will support completion of the advanced conceptual design of QPS.

In FY05, PPPL will support tasks planned for the first year of the QPS Major Item of Equipment project. PPPL responsibilities are:

- Design support and procurement, including associated manufacturing development and prototypes, for the modular coil winding forms. These components have a high degree of commonality with those of NCSX.
- Design support of the TF coils and center stack, which have a high degree of commonality with those of NSTX.

- Physics, engineering, and cost and schedule analysis in support of major reviews.

In 2006 through 2007, PPPL will continue to support the QPS project, taking advantage of Laboratory expertise and experience. In 2007 and 2008, PPPL will collaborate in QPS experimental research.

III.E. Off-Site Research

Performance of forefront research is the target of PPPL's Off-Site Research program; it addresses key scientific questions using leading facilities in the US and abroad, working as part of associated multi-institutional research teams. The motivation for PPPL's off-site collaboration program is that certain key US issues in fusion energy science require the use of off-site facilities, with unique capabilities. 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, resistive wall modes, neoclassical tearing 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; PPPL's off-site stellarator research is also key to the preparation of the PPPL research team for NCSX. 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.

Scopes of work that address key issues in fusion research have been developed for PPPL research 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), JT-60U (in Naka, Japan), and LHD (in Toki, Japan). These scopes involved detailed discussions between PPPL and the hosts of the remote program. Primary research 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.

DIII-D Project.

The programmatic foci are in the areas feedback stabilization of MHD modes, on understanding particle, energy and momentum transport in Advanced Tokamak (AT) regimes, and RF heating and current drive in AT regimes. These foci are strongly oriented toward supporting the overall DIII-D program goal of realizing the ultimate potential of the tokamak by establishing the scientific and technical basis for the design of a future steady state fusion reactor.

- 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 coupling PPPL theory codes to DIII-D data. The program on RWM control has achieved remarkable success recently in demonstrating plasma operation well exceeding the no-wall beta limit. The new

I-coil installation promises to advance understanding and control of RWMs to n=2 and n=3 modes.

- In transport, PPPL researchers are participating in the development of advanced diagnostics for the understanding of particle, energy and momentum transport in AT regimes. PPPL has recently invested in a new central CER diagnostic on DIII-D for the measurement of plasma toroidal rotation. Future upgrades will focus on a poloidal CER rotation diagnostic and on poloidal fluctuation measurements using reflectometry. Modeling of the diagnostic tools is a high priority for this collaboration, particularly for poloidal CER and poloidal reflectometry. In addition, modeling of the linear and non-linear microinstabilities will be performed in full plasma geometry using leading theory tools. The interaction of advanced diagnostic measurements with advanced simulation capability will be key to the way PPPL makes progress in developing a predictive transport capability.
- 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, and have recently succeeded in controlling the current profile in high performance plasma regimes. PPPL's role in the fabrication of these launchers is central to the success of the AT program. Future plans include two more launchers, including fast steering for real time steering control. In addition a new initiative has begun to upgrade the Fast Wave systems on DIII-D with the aim of controlling the core current density in AT plasmas for long pulse quasi steady state operation.

C-Mod Project

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. PPPL has a long history of involvement in lower-hybrid research and is collaborating with C-Mod to fabricate, install and operate a new C-Mod Lower Hybrid System.

- ICRF Heating and Current Drive:
  - Ongoing improvements have raised the ICRF power delivered by the PPPL-built 4-strap antenna to 3 MW. These improvements will raise the overall C-Mod heating power for both upcoming Advanced Tokamak and Burning Plasma experiments.
- Advanced Tokamak Physics:
  - The Lower Hybrid Launcher Upgrade Project has been completed. The launcher was delivered to MIT in April 2003 and will be installed after FY2003 C-Mod operations are completed. Off-axis Lower Hybrid current drive experiments form the basis of C-Mod's Advanced Tokamak program.
  - Rework of the MSE optical system to reduce disruption damage and advancements in the analysis techniques are starting to yield magnetic pitch angle measurements in conjunction with the Russian diagnostic beam. The resulting current distribution measurements are critical for current drive experiments on C-Mod.
- Turbulence and Transport Studies:
  - Edge plasma turbulence images obtained with the Gas Puff Imaging diagnostic are now being compared with various edge turbulence models. Understanding of the edge turbulence is expected to help in understanding edge transport, perhaps even core transport. Further diagnostic improvements as well as turbulence control experiments are being planned.
  - Careful comparisons of C-Mod core transport measurements with Ion Temperature Gradient models has shown that modifications to the model were required to match observations. Inclusion of nonlinear processes in these model calculations will be extended to help understand the role of turbulence in transport.
  - Linear and nonlinear calculations of gyrokinetic microturbulence have been carried out at the trigger time for formation of Internal Transport Barriers formed by off-axis ICRF heating in C-Mod. These calculations will be extended to aid in the understanding of ITB formation and behavior, which is an important facet of C-Mod's Advanced Tokamak program.

JET Project

The primary focus is on establishing the scientific and technical basis for a next step burning plasma experiment. This goal is accomplished through close collaboration with US domestic facilities and through involvement in the ITPA topical science groups aimed at establishing a coordinated and integrated framework for world-wide tokamak research. JET fulfills an essential role in establishing a basis for extrapolation of results from smaller facilities in the US and elsewhere to next step experiments. Areas of concentration are in energetic particle physics, fluctuations and transport, MHD stability, and RF heating and current drive. 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 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. Measurement and simulation of the current hole regime by PPPL scientists using advanced diagnostics and advanced simulation tools was a high point of PPPL site research in recent years and exemplifies the close coordination of theory and experiment aimed at advancing fundamental understanding and predictive capability.
- In transport, PPPL has installed a reflectometer system for measuring the characteristics of the plasma turbulence in JET. In concert, PPPL is involved in the non-linear simulation of microinstabilities to understand experimentally measured fluctuations and thermal fluxes.
- A key focus area for PPPL on JET is in alpha and energetic particle physics. PPPL is strongly involved in joint experiments to address the physics of fast ion driven instabilities in weak and reverse magnetic shear discharges. In addition PPPL is strongly involved in the JET-EP program through the contribution of a lost alpha particle detector array in collaboration with other US and EU collaborating laboratories.
- PPPL is engaged in a new collaboration with EFDA partners involved in developing a robust fast wave prototype antenna for JET and eventually for a next step burning plasma experiment.

JT-60U Project

On JT-60U, a major area of collaboration is in the development of negative ion beams required for central current drive and fast ion physics studies in JT-60U. This technology is ultimately aimed toward beam technology development for a burning plasma experiment. In addition, 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),
- MHD activity and disruptions.

Other Projects

- PPPL has designed diagnostic cassettes for the KSTAR superconducting advanced tokamak program in South Korea. In addition PPPL is engaged in developing an ECH microwave launcher.
- 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 is 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 has initiated an effort in analyzing the stability of current-carrying plasmas, relevant to NCSX physics.

III.F. Technology and Design Development

Technology and design development plays an important role in supporting the laboratories research objectives. The design of the laboratories major projects has been the responsibility of the Advanced Projects Department while technology development is distributed among departments. The Advanced Projects Department is responsible for the NCSX project discussed in Section III.D, and the PPPL activities on developing a US burning plasma experiment (FIRE) discussed as part of the Burning Plasma initiative in Section IVA. The remaining Advanced Projects design and laboratory technology development activities are discussed in this section.

Power Plant Studies: PPPL has participated in the national ARIES Power Plant studies, 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 has been initiated that will continue for several years. During FY03 the primary PPPL activity was physics tool development and scoping studies of a range of physics design points. The modest rate of funding for this activity will make it necessary to continue the physics design point development through FY04. If funding is available the design point will be selected by the end of FY04 and fully developed during FY05 and FY06. Beyond this time frame, PPPL advocates further work on the fusion development path, including the Component Test Facility and non-tokamak power plant 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 fusion technology programs. The PPPL Advanced Projects Department contribution addresses physics and engineering issues related to liquid first walls.

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 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. Examples of recent hardware developments include low-cost, high performance integrators for magnetics measurements, and low-noise, high-bandwidth preamplifiers for detectors used in Thomson scattering systems.

Under a DOE-funded program for innovative diagnostic development, the PPPL diagnostics division is engaged in several projects to produce new measurement tools for fusion research. Currently, there are three 3-year projects at PPPL funded from this program. PPPL is the lead in the development of 2-D detectors for imaging x-ray crystal spectrometry to measure profiles of ion and electron temperature. It is also the lead in the development of electron Bernstein wave radiometry as a fast electron temperature diagnostic for low field plasma devices. In addition, PPPL researchers are collaborating with the University of California at Davis (lead institution) in the development of microwave imaging reflectometry to image plasma turbulence. It is anticipated that PPPL would participate in similar diagnostic development programs in the future.

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 on-site and off-site research engagements, with ICRF antenna systems being provided for NSTX, C-MOD and JET, a LH launcher being constructed for C-MOD, and ECH/ECCD antennas being provided for DIII-D and KSTAR. Considerable effort is also being directed toward designing RF systems for other future devices. In particular, ICRF systems for NCSX, FIRE and ITER, ECH systems for NSTX and ITER, and LH systems for ITER are being considered.

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.G. Plasma Science and Technology

The Plasma Science and Technology Department (PS&T) 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 and 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: astrophysics, high-current high-energy accelerators and industrial applications.
- Developing near-term applications of plasma science that 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 Program in plasma 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 not only acceptable from an engineering standpoint, it produced a significant enhancement in plasma performance and a marked reduction in recycling. The next experimental phase will involve the installation of lithium-coated limiter plates on the center stack. The plates will be coated between shots with a 100-1000Å layer of lithium using a vacuum deposition technique, and the temperature of plate will be kept above the lithium melting point to insure a liquid plasma-facing surface. If it proves successful, this technique would permit implementation of a lithium particle control system on a large fusion device like NSTX. This approach to lithium PFCs is also prototypical of the lithium wall coating system envisioned for the Lithium Tokamak eXperiment (LTX). The LTX is a proposed new device that is designed to investigate the modifications to the ST equilibrium due to very low global recycling (<10%). Most of the existing CDX-U infrastructure would be used to build LTX. Success with the LTX experiments would point the way to a lower cost, more compact Component Test Facility and a fusion power reactor, based on the novel equilibria that are available through low recycling operation with lithium walls.

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 for Magnetic Self-organization" has been approved by the National Science Foundation. The Center arrangement is planned to lead to enhanced interactions amongst laboratory experimentalists, theorists from both the fusion and astrophysics communities, and observational astrophysicists. As a principal co-center of this effort, MRX will be funded by OFES for an upgrade of the facility and increased research efforts. In conjunction with the NSF center physics research, MRX research will put additional focus on physics topics, associated with magnetic reconnection and magnetic self-organization, that are of enormous importance to space, astrophysical and lab plasmas; dynamo, angular momentum transport, ion heating, magnetic chaos and transport, and magnetic helicity conservation and transport.

Theory and Experiments on Nonneutral Plasmas

These activities 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 key participants in the Heavy Ion Fusion Virtual National Laboratory (VNL). The long-term objective of the US 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 the emittance growth and beam losses are minimized in periodic focusing accelerators and transport systems for heavy ion fusion. Building on Princeton's considerable technical expertise, the Laboratory's participation in Virtual National Laboratory research activities focuses on: 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; experimental investigations of the effects of multi-electron loss events on heavy ion beam propagation, and the experimental test of negative-ion driver concepts for heavy ion fusion; development of novel rf source techniques for plasma formation and implementation at Berkeley on the Neutralized Transport Experiment to study collective beam-plasma interactions; 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; and participation as a full VNL partner in the design development, and eventual construction and experimental operation of the Integrated Beam Experiment.

Nonlinear Beam Dynamics and Collective Interaction Processes:

A fundamental understanding of nonlinear effects and collective processes in the propagation, acceleration, and compression of high-brightness, high-intensity charged particle beams for high energy physics applications is essential to the identification of optimum operating regimes in which emittance growth and beam losses are minimized. Collective processes and self-field effects become particularly important at the high beam intensities and luminosities envisioned in present and next-generation accelerators and colliders for high energy physics applications. Under the auspices of the Department of Energy's High Energy Physics Division, PPPL has established a vigorous theoretical and numerical simulation program in critical problem areas related to the basic equilibrium, stability and transport properties of intense charged particle beams. Over the next five years this program will include: application of the 3D nonlinear perturbative simulation code BEST to investigate detailed collective interactions and nonlinear processes in intense charged particle beams involving two charge components, with particular emphasis on the electron cloud and two-stream instabilities; application of the Vlasov-Maxwell equations to develop improved theoretical models of collective instabilities such as the wall-impedance-driven instability, temperature anisotropy instability, and microwave instability; develop improved kinetic models of beam-induced impedances and wake functions; and apply global conservation constraints to obtain nonlinear bound estimates on the emittance increase associated with collective instabilities.

The Magnetic Nozzle Experiment (MNX)

This Project investigates ion acceleration and detachment from an externally generated magnetic field as plasmas expand through a magnetic mirror field, the so-called magnetic nozzle. This small-scale experiment concentrates on atomic and plasma physics effects of low-β plasma and their applications to space propulsion, materials processing, and compact aneutronic fusion experiments. The same experimental equipment/facility will be used for the continuing FRC/RMF experiments.

FRC/RMF Experiment:

This is 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.

Plasma Applications

These activities 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

This function 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.

Paul Trap Simulator Experiment:

The Paul Trap Simulator Experiment has been constructed to simulate intense nonneutral beam propagation through a periodic focusing quadrupole field configuration, and experimental operation began in FY02. 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 interaction 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 include: detailed investigations of beam mismatch effects and envelope instabilities; investigations of collective wave excitations; investigations of chaotic particle dynamics and the production of halo particles; and determination of mechanisms for emittance growth, and the effects of the distribution function on stability properties.

Liquid Metal Laboratory Study of MHD Effects - 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: when and how do MHD effects modify surface stability, either in linear regimes or nonlinear regimes such as solitary waves? when and how do MHD effects modify a free-surface flow, such as by surface deformation? and 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.

Magnetorotational Instability (MRI) Experiment:

The experiment studies mechanisms of angular momentum transport considered to be important in accretion disks. Rapid angular momentum transport in accretion disks has been an outstanding problem in astrophysics for more than three decades. Classically estimated viscosity of neutral fluid is too small to account for the fast accretion rate accompanied by angular momentum transport. It has been recently recognized that MHD effects play important roles in this process. More specifically, MRI has been identified as a powerful mechanism to transport angular momentum. Although much theoretical and computational work has been done on this instability, there are no experimental studies on this subject. We will attempt to demonstrate and study this instability in the laboratory for the first time. Theoretical and numerical work indicates that the MRI can be triggered in a small rotating gallium disk with moderate speeds. The research carried in this experiment entails a close collaboration between laboratory experiments at PPPL and astrophysics led by Prof. J. Goodman at the Department of Astrophysical Sciences, Princeton University. The work by Prof. Goodman is supported by NSF and the work by PPPL is supported by DOE.

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:

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 2 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, NASA, 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.G.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. Through its Technology Transfer program the Laboratory encourages 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 an active member of the Federal Laboratory Consortium (FLC). The FLC is a Federally sponsored agency that promotes Technology Transfer training and partnering opportunities. The Laboratory maintains close contact with other DOE Energy Research Laboratories and other regional Federal 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 Application Research in the PS&T Department, 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.H. 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. Theory has played a lead role in the conceptualization and subsequent successful design of the NCSX. 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 covers a wide spectrum from very fundamental to directly applied studies. Fundamental investigations of the properties of plasmas provide the foundations upon which the applied studies are built. They have also lead to the 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, PPPL scientists have played a major role in providing plasma sciences with excellent theoretical foundations and seminal ideas. 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 increasing 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 capability for the associated plasma dynamics 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 efficient utilization of increasingly powerful supercomputers. 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 extending this high-level of confidence to the prediction of the non-linear saturation of fully three-dimensional plasma instabilities, developing techniques for the active stabilization of MHD modes, and 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 NSTX, the spherical torus will continue to receive increasingly greater attention as stimulating new experimental results continue to emerge. 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. 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 has enabled the successful design of the NCSX which includes 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, 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 novel 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 in need of interpretation. Research on important solar and astrophysical phenomena (coronal heating, accretion disk dynamics, etc.) are being actively pursued.

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 Program, the National Transport Code Collaboration, as well as the aforementioned lead role in the Plasma Science Advanced Computing Institute. Within Princeton University, in addition to productive collaborations with various departments such as Mechanical and Aerospace Engineering, Computer Science, Applied Math, and others, PPPL theory is also actively involved in the university's new Princeton Institute for Computational Science and Engineering.

Finally, motivated by the 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 modern computational platforms, 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 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 PPPL leadership mission. It is also an excellent vehicle for interacting with other disciplines, including academic departments and institutes at Princeton University, and for developing presentations at multi-disciplinary computational physics conferences. An excellent recent example of productive alliances with Princeton University academic departments is the exploration of modern grid computing capabilities via partnership in a pilot OFES Topical Computing Facility at PPPL. The graduate program at PPPL also serves as a natural vehicle to effectively disseminate specialized computational physics knowledge outside of PPPL. A significant 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 is a program supported by a major NSF grant to support graduate student internships in applied scientific computing. It focuses 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. This change has come about largely because the newest workstations available now are faster on most scientific applications than are the "supercomputers" at NERSC, and are also considerably more cost effective. PPPL supports a Linux Beowulf cluster, PETREL, which now has been upgraded to 200 processors. 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 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 been funded to begin investigations leading to a Topical Computing Facility for Fusion Energy Science. The prototype facility is a 128 processor cluster system with a fast interconnect, which supports a number of the key FES 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 (in collaboration with Princeton University and GFDL) and develop large-scale between-shots data analysis capabilities in support of experiments. Possible development of a Princeton Computational Resource Center (PCRC) in collaboration with Princeton University and the Geophysical Fluid Dynamics Laboratory could lead to major enhancements of computational capabilities which would be of significant benefit to PPPL's missions.

III.I. 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.

An 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.J. 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 current projects funded include:

Project (Investigator)
Advanced Lithium Wall Coatings for Fusion Experiments (Majeski)
Next Step Spherical Torus Exploratory (Ono)
Dynamic Modeling of Neurophysiological Experiments for Space Plasma Systems (Johnson)
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.K. Education

III.K.1. Science Education Program

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

- Provide opportunities for students and teachers to engage in scientific inquiry in ways that enhance their understanding of science concepts and scientific ways of thinking.
- Provide innovative opportunities for educators to work together and 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 for the concepts embodied in the National Science and Math Standards.
- Communicate current scientific knowledge, especially that about fusion energy sciences, to members of the community, and to extend this effort more broadly using communications technology.

This mission is implemented through a number of programs that include:

- National Undergraduate Fellowship Program in Plasma Physics and Fusion Energy Sciences gives outstanding undergraduate students in US colleges and universities an opportunity to participate in projects at the forefront of R&D of fusion energy.
- Partnership with Trenton Public Schools and local communities around PPPL is a collaborative effort to improve math, science and technology education. A key objective 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 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.
- Science Undergraduate Laboratory Internship 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 DOE regional competition hosted by PPPL for high school students. The 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.

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 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.K.2. Graduate Education

The Graduate Plasma Physics Program was first offered at Princeton University in 1959. 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.

Members of PPPL's research staff, including three Princeton University Professors, who comprise the fifteen-member plasma physics faculty teach many of the required courses. 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. 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 FY02-03 are shown in Table 13.

Six students in residence during FY03 held prestigious fellowships: three Fusion Energy Sciences Fellowships, one Hertz Fellowship, and one national Defense Science and Engineering Graduate 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-ten scientists have received doctoral degrees through the Princeton 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 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.

IV. Summary of Major Initiatives

PPPL is proposing one major initiative: involvement with a burning plasma experiment. This project is included for funding in the President's budget for FY04 with significant increases in FY06 and beyond. Other projects are under consideration, but are not yet ready for formal proposal (some of the smaller items are listed in the earlier text). 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. Burning Plasma Experiment/Program

Overview

PPPL seeks to enable US community participation in the study of burning plasmas, which have been recognized as a major next step for the world fusion program by the 2002 Snowmass Fusion Summer Study, the FESAC Burning Plasma Strategy study, and the National Research Council's Burning Plasma Committee. The critical physics issue for an attractive magnetic fusion power plant is whether a burning plasma that is self-heated by the fusion process and has a self-driven plasma current can be created and controlled in the laboratory. Based on its interest in burning plasmas, in project and program management, and in facilitating US community involvement in programs, PPPL offers to serve as the host institution for US burning plasma studies.

Policy Aspects

Several recent US activities have re-affirmed interest in Burning Plasma Physics, the third element of the restructured US fusion Program. In August 2001, FESAC endorsed the finding that "Now is the time to initiate the construction of a Burning Plasma Experiment" and recommended a community wide meeting to assess the status of burning plasma physics and the capabilities of the three present burning plasma experiment designs: ITER, FIRE and IGNITOR.

At the 2002 Fusion Summer Study at Snowmass of nearly 300 fusion scientists, there was a strong consensus behind the central finding. "The study of burning plasmas, in which self-heating from fusion reactions dominates plasma behavior, is at the frontier of magnetic fusion energy science. The next major step in magnetic fusion research should be a burning plasma program, which is essential to the science focus and energy goal of fusion research." Working groups also provided a very positive assessment of the ITER and FIRE mission and capability. Most importantly, the Technical Assessment concluded that there are no outstanding engineering-feasibility issues to prevent the successful design and fabrication of ITER or FIRE, and that there is confidence that ITER and FIRE will achieve burning plasma performance in the conventional H–mode. Based on 0D and 1.5D modeling, all three devices have baseline scenarios which appear capable of reaching $Q = 5 - 15$ with the advocates' assumptions. ITER and FIRE scenarios are based on standard ELMing H–mode and are reasonable extrapolations from the existing database. A number of technical issues were identified and documented in the body of the Snowmass report. These issues are the subjects of continuing R&D. In addition, Snowmass also reviewed the development paths based on either ITER or FIRE and concluded that they were somewhat complementary and each had advantages and disadvantages.

In September 2002, FESAC recommended to DOE a Dual Path strategy developed by a FESAC Panel consisting of 44 fusion community leaders. FESAC found that:

- ITER and FIRE are each attractive options for the study of burning plasma science. Each could serve as the primary burning plasma facility, although they lead to different fusion energy development paths.
- Because additional steps are needed for the approval of construction of ITER or FIRE, a strategy that allows for the possibility of either burning plasma option is appropriate.

Since ITER is at an advanced stage, has the most comprehensive science and technology program, and is supported internationally, the US should now seek to join the ITER negotiations with the aim of becoming a partner in the undertaking, with technical, programmatic and timing considerations as follows:

- The desired role is that the US participates as a partner in the full range of activities, including full participation in the governance of the project and the program. We anticipate that this level of effort will likely require additional funding of approximately $100M/yr.
- The minimum acceptable role is at a level of effort that would allow the US to propose and implement science experiments, to make contributions to the activities during the construction phase of the device, and to have access to experimental and engineering data equal to that of all partners.
- The US performs a cost analysis of US participation and reviews the overall cost of the ITER project.
- The Department of Energy concludes, by July 2004, that ITER is highly likely to proceed to construction and terms have been negotiated that are acceptable to the US. Demonstrations of likelihood could include submission to the partner governments of an agreement on cost-sharing, selection of the site, and a plan for the ITER Legal Entity.

Since FIRE is at an advanced pre-conceptual design stage, and offers a broad scientific program, we should proceed to a Physics Validation Review, as planned, and be prepared to initiate a conceptual design by the time of the US decision on participation in ITER construction.

- If ITER negotiations succeed and the project moves forward under acceptable terms, then the US should participate. The FIRE activity should then be terminated.
- If ITER does not move forward, then FIRE should be advanced as a US-based burning plasma experiment with strong encouragement of international participation.

PPPL's Plan for Burning Plasma Studies

Consistent with the FESAC and DOE strategy of a dual-path to the study of burning plasmas, PPPL is engaged in leading roles in both FIRE and ITER.

Plan for Participation in ITER

Since the US has now begun participating in the international discussions on ITER and since preparations for ITER discussions involve a wide range of aspects, DOE/OFES appointed a PPPL manager as the ITER Planning Officer with a university manager as deputy. A Burning Plasma Advisory Committee, reporting to the US ITER Planning Officer. Near-term activities focus on support for the US negotiators and community outreach.

The first negotiation-support activity involves leading a community activity to estimate the US cost of performing interesting procurement scopes, which have been specified by the ITER Team and used as the technical and cost basis for ITER. At the end of FY03, the cost estimates for Diagnostics, Ion Cyclotron, Electron Cyclotron, Central Solenoid Coil, and Divertor systems will have been completed and reported to DOE. This information will enable an estimate of the ratio of US ITER cost to credited ITER value for these scopes. This information will be fed into DOE estimates of the range of project-fractions that the US can offer during Negotiations based on a US dollar limit.

PPPL will participate in NSSG meetings to aid the governmental delegates in preparing joint working papers on topics such as management, procurement systems, procurement allocations, staffing, financial regulations, etc. Also important is discussions of the criteria for the allocation of ITER run-time. PPPL will work toward having scientific merit be the primary criterion for run-time allocation.

The Burning Plasma Program Advisory Committee is being involved in commenting on draft working papers as they evolve. In the area of outreach, an ITER Forum has been held to solicit input from the fusion community on participation in ITER.

If the US joins ITER Transitional Activities, which is expected, then PPPL offers to manage involvement in US participant team design and R&D activities. Management of this work will involve working with the Central Team to define and conduct specific design and R&D work, in support of the ITER design and manufacturing activities. PPPL would also likely offer secondees in appropriate areas of interest to the US.

If negotiations on ITER Construction reach an acceptable outcome, then the US will need to develop its Project Execution Plan, detailing how the US work scope would be executed. The Dan Lehman-led US ITER Cost Study identified the importantance of excellent management both in the international team and in the US team for ITER to be successful and for the US to benefit from its ITER investment appropriately. PPPL would offer to support the US Field Team, a remote component of the ITER Central Team that interacts with the US Domestic Agency and with the vendors performing ITER work in the US.

PPPL would also seek to participate in ITER program activity, which complements the design activity and works toward ITER research operations. PPPL would perform experiments, theory and modeling (ITPA and joint experiments), and R&D and design of diagnostics, heating and current drive. As a key part of this activity, PPPL would seek to lead positioning the US to prepare and submit the highest quality proposals for scientific research, thereby gaining access to ITER as a leading scientific research facility; such research planning and proposals would demand world-class tools for developing plasma scenarios, modeling and experiment-design tools, and remote participation tools.

Plan for Preparation of FIRE

The Fusion Ignition Research Experiment (FIRE) design study has been undertaken to define a low cost domestic facility to attain, explore, understand and optimize magnetically-confined fusion-dominated plasmas. The FIRE Design study has been a national collaboration with participants from more than 15 US institutions and managed through the Virtual Laboratory for Technology. The technical work on FIRE has been guided by a Next Step Option Program Advisory Committee (NSO-PAC) with members from 12 US fusion institutions and as well as Europe and Japan.

The overall strategy is to continue to advance the design of FIRE in accordance with the FESAC recommendations while providing support on generic burning plasma issues that will benefit ITER as well as FIRE. FIRE is planning a Physics Validation Review in September 2003 to provide assess the technical issues raised by the Technical Assessment at Snowmass and by the NSO-PAC.

FY 04 – the FIRE focus would be to respond to PVR chits and recommendations, and to extend advanced capability to both physics and technology. Specific activities would include:
- Demonstrate feasibility of an ARIES-like AT Scenario for FIRE (and ITER)
- Extend analyses of RWM stability and RWM coil feasibility with compatible PFCs
- Optimize PFCs to extend performance of FIRE and ITER vs. ARIES
- Develop RWM technology (insulation, feedback control,..) for FIRE and ITER vs. ARIES
- Disruption Mitigation Development for FIRE and ITER vs. ARIES
- Plasma Engineering (ICRF, LHCD, Pellets, ..) with aim to FIRE and ITER vs. ARIES
- Diagnostic Development for FIRE and ITER (AT Physics parameters)
- Collaborate with SCIDAC Fusion Plasma Simulator on BP simulations.

FY 05 – This is the year for a decision on ITER construction according to international plans that call for ITER Construction authorization by July 2005. In the case of successful ITER negotiations, the US would join the ITER Construction Project. In the opposite case, a US National FIRE Design Team would be formed and the US would initiate Conceptual Design Activities on FIRE. Prior to this decision important technical activities of benefit to either outcome would include:
- Demonstrate a viable disruption mitigation technique suitable for FIRE or ITER vs. ARIES-RS
- Demonstrate a PFC configuration design with suitable heat loads and tritium inventory for FIRE or ITER vs. ARIES-RS
- Plasma Engineering (ICRF, LHCD, Pellets, ..) with aim to FIRE or ITER vs. ARIES
- Diagnostic Development for Burning Plasmas

Generic Burning Plasma Activities

The US is actively participating in the International Tokamak Physics Activity (ITPA) to address burning plasma issues. Progress in burning plasma physics issues could be enhanced by forming US Task Forces focused on critical burning plasma issues of interest to the US such as:
- Optimization of an advanced tokamak burning plasma
- Development of high power reactor relevant plasma facing components
- Control tools (current drive, fueling fast position control) for burning plasmas
- Disruption mitigation and avoidance techniques
- Burning plasma diagnostic development

The rapid growth in computing power is enabling more realistic simulations of complex plasma phenomena. The Scientific Discovery using Advanced Computing Initiative could be focused to provide a virtual burning plasma capability that would be of benefit during the design, and operation phases of a burning plasma experiment. It would also carry the generic physics to benefit burning plasma experiments in other magnetic configurations.

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, including 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 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 Office of Science Advanced Computing Programs:

The major goal of the Fusion Energy Sciences element of the DOE-SC SciDAC Program is to develop and deploy advanced computational methods, capable of making optimal use of terascale 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 as well as in new algorithms and improved software. The PSACI is a distributed national center 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 Program Advisory Committee are composed of leading scientists from a broad range of institutions both within and outside the plasma physics discipline. The funding of SciDAC projects is expected to be handled in a peer-reviewed grant applications process managed by OFES and assisted by the PSACI. PPPL scientists are also actively involved in the development and planning for future large-scale computational initiatives such as the national Fusion Simulation Project, which targets the integrated modeling of toroidal magnetic fusion devices.

Topical Computing Facility for Fusion Energy Sciences

Within DOE's Office of Science there is an identified need for cost-efficient topical computing facilities focused on the computational needs of specific scientific applications, such as Fusion Energy Sciences. PPPL has been selected by OFES to host a Pilot Topical Computing Facility (TCF) for Fusion Energy Sciences. It is an ideal site for a topical computing facility in view of: its experience with the Pilot TCF, which includes a productive active collaboration with Princeton University to explore grid computing; its lead role in the PSACI activities; its strong historical role in computational plasma physics, including the establishment of a successful Computational Plasma Physics Group; and its continuing productive activities in developing a production scientific computing environment addressing key capacity computing issues with extensive experience in the deployment of modern clusters and advanced visualization capabilities, including the deployment of a high-resolution display wall (developed in collaboration with the Computer Science Department of Princeton University). Currently the Laboratory is exploring the development of a computational resource center in partnership with the nearby NOAA Geophysical Fluid Dynamics Laboratory and Princeton University. PPPL has the engineering resources and expertise to operate 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 other FES research centers.

Princeton Computational Resource Center

Currently, PPPL is exploring the development of a jointly operated Princeton Computational Resource Center (PCRC) in partnership with the nearby NOAA Geophysical Fluid Dynamics Laboratory and Princeton University [through its new Princeton Institute for Computational Science and Engineering (PICSciE)]. This would be an interagency-supported facility with a FES TCF as a major component. The principal motivation is to create a first-class supercomputing facility which would enable an attractive cost-effective sharing of infrastructure as well as of scientific computational expertise impacting both the computer science and physical science applications of vital importance to the participants and their respective research funding agencies. It would require the joint support of the Department of Energy (DOE), the Department of Commerce (DOC), and Princeton University (PU). This partnership leverages investments from these institutions and has received strong interest and encouragement at high administrative levels at the DOE, the DOC, and the OSTP. A jointly-operated center located on Princeton University's Forrestal Campus at C-site can provide unique mutual benefits for PPPL, GFDL, and PU. In addition to enabling effective sharing of computational resources and expertise in both the computational and physical sciences among these institutions, the development of and subsequent access to a high-quality experienced support staff would be greatly valued by Princeton University's research faculty in Astrophysics, Mechanical and Aerospace Engineering, Geosciences, et al., and GFDL. The establishment of the PCRC at C-site would provide a very attractive leveraging of existing infrastructure and expertise at PPPL including security experience and project management of large engineering systems. With proper funding support, PPPL could effectively host 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 other FES research centers. In general, complementary to its involvement in "capability computing" activities on the most powerful available supercomputing platforms at major centers [e.g., at the National Energy Research Supercomputing Center (NERSC) at Berkeley and at the Oak Ridge National Laboratory (ORNL)], the pilot TCF is currently addressing important "capacity computing" issues by examining the cost-effective utilization of commodity clusters dedicated to key FES applications. This involves collaborations with several national FES computational research teams and the active exploration of the potential advantages of grid computing with Princeton University and GFDL. Grid computing is a distributed computing infrastructure for advanced science and engineering applications involving large-scale resource sharing. This includes not only file exchange, but also direct common access to computers, software, data, and other resources. Together with funds from the Provost's office, from a number of Main Campus departments (MAE, Astro, Geosciences), and from PICSciE, PU provided matching funds for this DOE project with focus on the grid computing explorations scope. GFDL later joined this collaboration with investment in an 16-node (32-processor) dedicated cluster which is architecturally compatible with the PPPL/PU component. Knowledge gained through this pilot project on both capability and capacity computing issues will be applied toward planning a full Fusion Energy Science TCF, which would be a major component of the PCRC. In a collaborative interagency sense, such activities are also very much in line with the primary interests and investments of the National Science Foundation (NSF) in high-performance computing.

IV.C. Next-Step Spherical Torus

Due to the encouraging results from ST experiments such as the NSTX and the Mega-Amp Spherical Tokamak (MAST) in the U.K., an initial engineering and physics design assessment of a Next-Step Spherical Torus (NSST) device was carried out. NSST is envisioned as a “performance extension” stage ST with the plasma current of 5-10 MA, a significant step from the above-mentioned “Proof-of-Principle” devices with the 1-2 MA capability. The primary mission elements of NSST are to provide sufficient physics basis at multi-mega-ampere plasma currents, including solenoid-free start-up and sustainment, to:

- Enable the design and construction of a compact Component-Testing-Facility (CTF);
- Explore advanced physics and operating scenarios of sustained ST regimes with high bootstrap current fraction and high performance at the multi-mega-ampere plasma current range, which can be transferred to optimization of CTF, DEMO, and/or Power Plants;
- Expand the existing tokamak data base at low aspect-ratio regime to further improve the theory and modeling understanding and predictive capability; and
- Contribute to the general plasma and fusion science of high temperature, collisionless, high β toroidal plasmas for the Innovative Confinement Concept as well as astrophysical plasma science of solar, space and stellar plasmas.

The NSST is envisioned to be 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. This high beta alpha physics information could prove to be invaluable for the design of DEMO which is expected to operate at considerably higher plasma beta than the planned tokamak burning plasma experiments such as ITER. To support an accelerated fusion energy development path recommended recently by FESAC, the design and construction of the NSST facility can be started as early as 2007. The NSTX research plan proposed for FY04 – 08 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 Environment, Safety and Health (ES&H) program that continues to seek improvement based on operating experience, lessons learned and continued attention to elements of Integrated Safety Management (ISM).

In CY02, the TFTR D&D Project was completed including segmentation of the vacuum vessel itself. There were no skin or clothing contamination events, and the total effective dose equivalent to our employees was limited to 3.707 person-rem. Both measures are considered "Outstanding" performance under our contract with DOE.

ES&H Goals and Issues

PPPL complies with 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. The Laboratory policy is to take all reasonable precautions in the performance of tasks to protect personnel, visitors, neighbors, property, and the environment from injury.

As one indication of the success of ES&H, PPPL measures and tracks the following OSHA Case Rate statistics:

	Recordable Injury Case Rate		Away from Work Lost Work Day Case Rate		Away from Work Lost Work Day Rate	
Cal. Yr	Goal	Actual	Goal	Actual	Goal	Actual
01	1.5	5.24	0.5	0.95	15	31.92
02	0.0	2.83	0.0	0.50	0	5.82

In 2002, there was a significant decrease in the frequency and severity of recordable injuries compared with 2001. Initiatives aimed at increasing worker awareness, skills, and safe work performance were continued and expanded. These initiatives include:

- More frequent workplace inspections by line management and oversight personnel.
- Continuation of the lessons learned program, which communicates to the staff discussions of ES&H incidents within and outside PPPL.
- Annual “stand downs” of work activities to involve workers in discussions on ES&H issues.
- Initiation of a monthly ES&H newsletter that provides a vehicle for supervisors to address ES&H topics of interest with their staffs.

Overall, the Laboratory’s ES&H record has been good and PPPL will continue to strive for exemplary performance in this area.

Current Conditions

ISM 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. 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 of Laboratory facilities are conducted 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.

PPPL reviews requirements and institutes 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.

PPPL is making preparations for possible external regulation of occupational safety and radiation protection by the Occupational Safety and Health Administration (OSHA) and the Nuclear Regulatory Commission (NRC), respectively.

V.B. Communications and Trust

Fusion's promise is an energy source that will be better for the world via a process that is safe and environmentally attractive. PPPL assures that its research activities do not compromise that vision. 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. An individual can send 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.
- 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 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 scientific 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. Human Capital

The Human Resources (HR) group has established itself as a strategic partner and critical consultant to the Laboratory Director, Deputy Director and line management in the areas of recruitment, employee relations, compensation, staff training and development, benefits management and effective use of human resource technology. The HR group will face several complicated challenges in the future that will require new approaches and business acumen.

- We continue to make PPPL an attractive collaborative center while implementing the DOE

enhanced controls related to visits and assignments by foreign nationals. In addition we will be required to address other visitor issues regarding housing, benefits and medical coverage.
- Over the next three years, nearly 20 % of the PPPL population will be age 62 or older. As employees begin to retire, a major challenge facing HR will be capturing core business knowledge of the staff before they retire and to hire the next generation of scientist and engineers to support the work of the Laboratory.
- During the same period, over 45% of the PPPL population will be age 55 or older and also eligible for retirement. The health of our employees will be a major concern. Working within the university system, we will continue to support efforts that will insure that we have the right blend of high quality benefits that are affordable.
- Continue our succession planning process with phased-in retirement to assist while planning for impending retirements. We must create an opportunity for new individuals to be trained so that core institutional knowledge will not be lost.
- Explore alternative ways to classify employees or decide if we will continue to support our current classification system.
- Increases the number of web based training courses and examine the benefits of web base verses instructor led training courses.
- Design and support a work friendly environment that centers on the growing diversity in the workforce and the well being of all employees.
- Continue to support the PeopleSoft 8 Human Resources Management System to manage our HR business processes.

Significant accomplishments occurred at the Laboratory during fiscal years 2000 through 2002, including the Decommissioning and Decontamination (D&D) of the Tokamak Test Fusion Reactor (TFTR). This required hiring a large number of Engineers, Technicians, Health Physics Technicians and Clerical staff to support the project. Non-traditional hiring strategies were used to recruit and expand our resources. Community organizations, professional associations, military newspapers and the Internet were some of the sources used to help increase our recruiting effectiveness and the diversity of our applicants. Additionally, several individuals were hired from the New Jersey Welfare to Work Program.

During that period, we succeeded in hiring 135 employees; of that 18% are women and 21% minorities. Approximately 60% of the hires supported the D&D Project.

We anticipate level staffing during the next several years. Consequently, we do not expect any major recruiting activity at PPPL. However, from our experience with the D&D Project, we have established best practices in employment and remain committed to activities that demonstrate and support our policies as they relate to affirmative action, equal employment opportunity and diversity.

Every attempt is made to provide all employees with the necessary tools to succeed at PPPL. Through our programs and constant communication we will continue to implement strategies that close gaps, measure results, provide education and improve communications at the Laboratory.

V.D. Site Facilities and Infrastructure Management

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 ~ 725,000 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 27 buildings on C-Site, 8 buildings on D-Site and 1 Off-Site pump house.

The C-Site complex, including theoretical, administrative, research, experimental and technical operations activities, is structurally sound. Throughout C-Site office space is fully utilized and during certain peak periods in the summer office space is at a premium. A proposal has been submitted to DOE to construct an Lyman Spitzer Building (LSB) West Wing Addition similar to the LSB East Wing Addition. The proposal has been submitted for funding consideration in the Science Laboratory Infrastructure (SLI) program. The addition would modernize the facility by replacing

Module 6, the Theory Wing and part of the Administration Building. Each of these buildings has a Summary Condition Code of ‘Fair.’

During FY02, the 2nd floor of the Emergency Services building was converted to sleeping quarters for security personnel, greatly improving the quality of quarters for the staff. Administrative and technical support personnel within the Site Protection Division were relocated to Module 6.

The D-Site complex, including experimental, office and support space built in the 1970's to support TFTR currently supports the NSTX experimental device. Decontamination and Decommissioning (D&D) of TFTR was successfully completed in FY02, and there are no plans for near-term major renovations at D-Site. 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.

The 10-Year Strategic Facilities Plan describes the existing site and infrastructure and planned construction for the next ten years. During FY02, the Laboratory updated this Plan. Data related to the condition, use and age of Laboratory facilities are shown in Figures 1, 2, and 3. Presently, there are two buildings at PPPL with a Summary Condition Code of ‘Fail.’ The first of these is the C-Site Cooling Tower and Pump house, and the second of these is the Off-Site Canal Pump house. Both buildings have a high cost of deferred maintenance relative to replacement value, and plans are underway to address these deficiencies.

Laboratory Site and Facilities Trends

As Laboratory’s funding compared to a decade ago has declined and as a consequence maintenance funding has also declined. Maintenance spending on buildings in FY02 was $2.9 million against building replacement value of $221 million. The operating budget for facility maintenance has been less than that seen in industry. Laboratory management has focused on this as an area requiring increased attention and is discussed further in section resources section below.

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 in 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. This Plan was updated early in FY03. The modernization effort focuses 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 at the annual 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. 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.

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. During FY03, the site-wide effort begun two years ago to replace underground transite potable and canal water lines will be completed.
- A sequential program of roadway rehabilitation will be coordinated over the next five years. 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 physical security systems are 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. Funding for this project has been approved as of May 2003.

Detailed General Purpose Facilities Plans and Facilities Resource Requirements

Laboratory funding has remained essentially flat for the past several years. The operating budget for facility maintenance remains constrained, and as a result, the number of deferred maintenance items is rising. 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 FY02, annual maintenance expenditures (excluding steam plant operation, landscaping, snow removal, and janitorial budgets) are approximately 1.3% of the facility Replacement Plant Value as compared to 1.1% reported last year.

Maintenance priorities are established on a fundamental basis that relies heavily on the knowledge and experience of in-house engineers and technicians. Priorities are established to address work tasks that: affect environment, safety, health or security issues; are directly related to facility operations; require immediate action to restore equipment to operable status; and provide preventive maintenance to operate the facilities in an efficient manner. Typically, 2000 to 2500 routine work orders are completed in a given fiscal year. A new Computerized Maintenance Management System was installed and has been operational since October 2002. This new system greatly enhances the ability to track and trend maintenance activities.

PPPL uses a GPP Prioritization Procedure for assessing and prioritizing proposed Projects. The Technical Resources Committee (TRC) 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 led to the initiation of a conceptual design to study the benefits of erecting a single, new 3-story building (LSB West Wing Addition) and therefore eliminating 3 separate singlestory 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.

Assets and Space Management (Inactive Surplus Facilities)

Departments are not charged for space utilization. The Maintenance and Operations Division and Facility Managers throughout the organization manage space. During FY03, property management personnel continued to review and dispose of property that is no longer needed to support current or planned PPPL operations. 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.

Energy Management

The In-House Energy Management Program includes 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. 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.E. Security, Intelligence and Nonproliferation

PPPL strives to ensure that its employees, collaborators, visitors and the general public work have a safe and secure environment at the Laboratory through an Integrated Safeguards and Security Management approach. The 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. Increased attention to physical security controls has resulted in a significant impact on the Laboratory's Security Program.

These controls included additional security patrols, enhanced access controls, and several modest facility improvements. PPPL has worked closely with the DOE on budget issues to ensure that security needs are met.

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.

VI. Summary of Major Issues

Five major issues have been identified for discussion at the on-site review. They are outlined here to provide background for the discussion.

PPPL's Role in ITER

PPPL management has devoted considerable attention and resources to supporting the Administration's decision to join the ITER negotiations. PPPL has also provided the ITER Project Officer for the preliminary phase of US involvement and has supported much of the preparatory work for negotiations. It is important to define PPPL's future role in the ITER project so that preparations can be made to perform that role effectively.

Domestic Research and ITER

The US needs to be competitive in fusion research. Participation in ITER is a necessary but not sufficient ingredient in this competitiveness. It is critical that the US capitalize on its strengths in science and innovation, to position the US to take advantage of ITER participation and to prepare it to develop practical fusion energy systems. Fuller utilization of NSTX, measured not only in terms of run weeks but also in terms of improved scientific capabilities, and prompt construction of NCSX are needed to accomplish this goal.

The incremental proposals within this Institutional Plan are focused on the twin goals of science and innovation, leading to practical fusion energy. The cost-effectiveness of these incremental proposals can be identified by comparing the ratio of direct to support staffing in the baseline FY2005 budget case (1.8:1) to the ratio in the same year of the incremental direct staffing to incremental support staffing (11:1). Since overhead rates are dominated by labor costs and fixed institutional expenses, incremental activities at PPPL are evidently very cost effective for the DOE Office of Science.

Project Management at PPPL

DOE, Congress and the National Research Council have focused attention on project management at DOE and in the DOE Office of Science. Despite the success of the major TFTR D&D Project at PPPL, other projects have encountered difficulties with cost, schedule and/or performance. This is a strong focus of management attention. New initiatives to improve project management performance at PPPL will be described. A key factor which has drawn management attention is the development of mechanisms for risk management, driven at the technical end by identification of all significant risks to cost, schedule or performance, and driven at the programmatic end by all potential programmatic impacts and DOE and DOE-SC accountability measures.

West Wing Addition / Scientific Laboratory Infrastructure Funding

The Laboratory has identified a responsible long-range plan for maintaining and steadily improving its infrastructure. However this plan depends upon PPPL's receiving a yearly-averaged Scientific Laboratory Infrastructure funding of $2.7M/year as specified in Table 3, approximately 6.4% of the current magnitude of this DOE-SC funding stream.

Princeton University and the NOAA Geophysical Fluid Dynamics Laboratory have developed a proposal for a new "West Wing Addition" to the Lyman Spitzer Building. Princeton University would finance a substantial portion of this addition, in order to allow the placement there of a significant computer facility that could be used by Princeton, GFDL – and DOE if it so chose. Such a shared facility could cost-effectively provide advanced computing capabilities to these three communities, meeting the perceived need of the Government to save resources through inter-agency cooperation and providing an opportunity for valuable interdisciplinary cross-fertilization in the area of computational science.

External Regulation

It appears likely that PPPL and the other DOE Science Laboratories will be transferred to external regulation via the NRC and OSHA. Three issues of importance need management attention in this area. First, it is imperative that this change not result in double regulation, in which DOE is interposed between PPPL and the external regulators. This seems to us a very likely outcome of the initiative, and it must be avoided. Second there may be significant funding requirements at PPPL, and particularly at other Laboratories, needed to respond to the different requirements of these agencies as compared with DOE. An assessment of these funding requirements will be made after the OSHA and NRC reviews this summer. It is imperative that funding for these changes be requested from Congress in a manner which does not impact program funding. Finally, with encouragement from DOE-SC, PPPL has significantly improved its safety record. We consider it imperative that the external regulation initiative not distract line managers and safety professionals from sustaining and continuing to improve this safety record.

VII. Resource Projections

Table 1. PPPL Program Plan

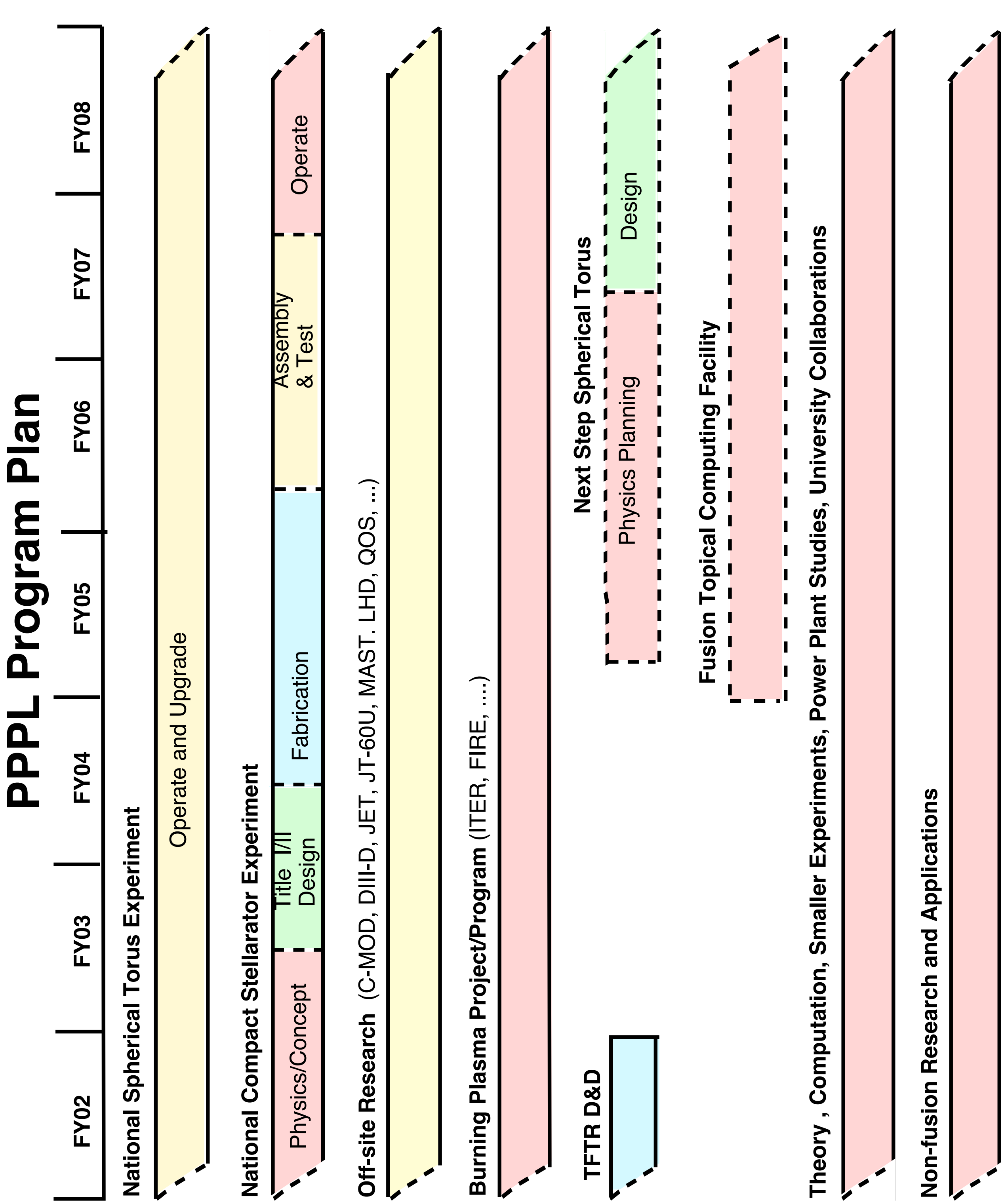


Table 2. Organization Chart

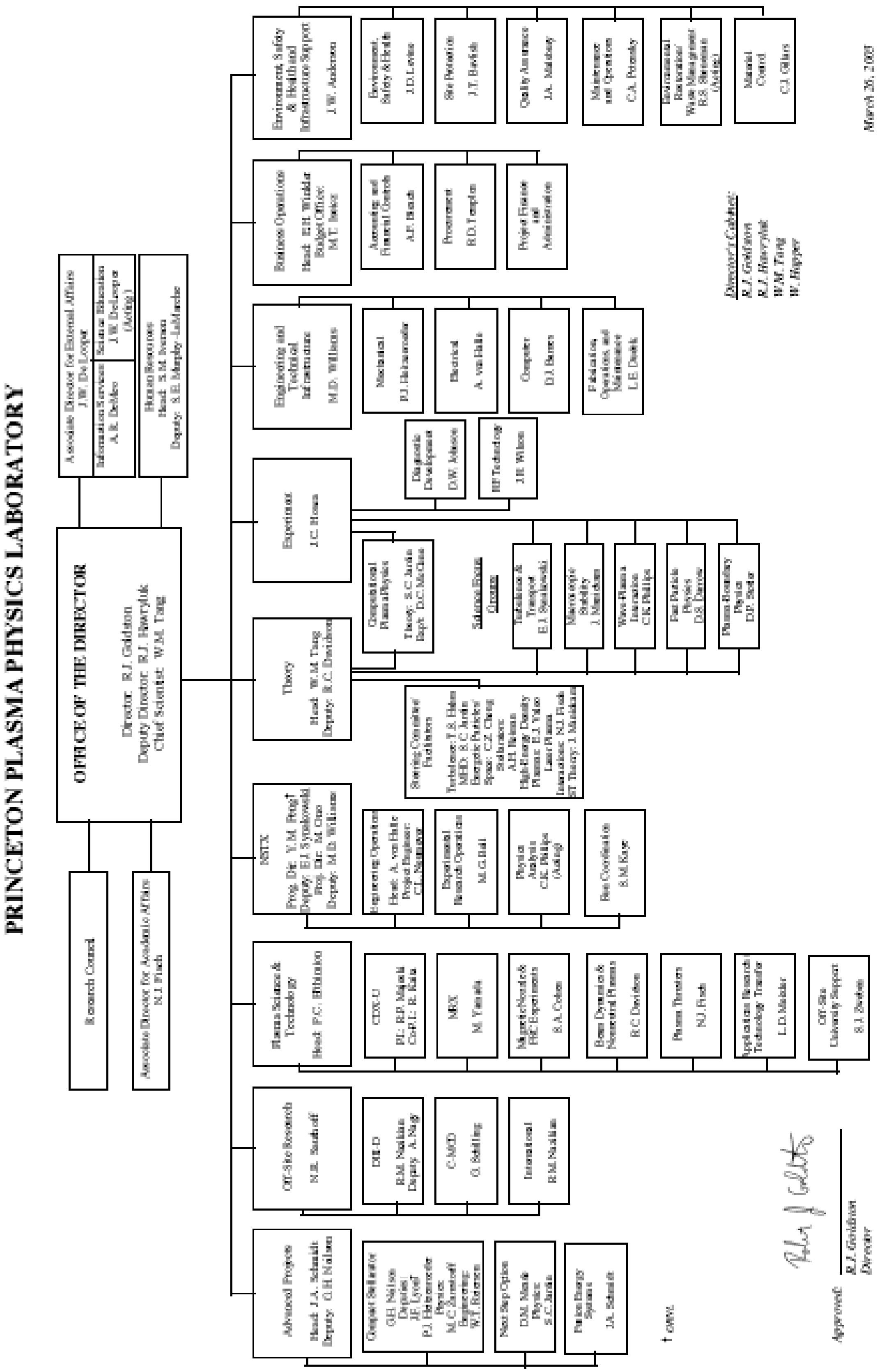


Table 3. Laboratory Funding Summary

Current Year Dollars ($M)

AT-Fusion Energy Sciences	**FY03[1]**	**FY04**		**FY05**		**FY06**		**FY07**		**FY08**	
On-site Research	**Base**	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**	**Base**	**Incr.**
NSTX (PPPL)	25.9	30.4	3.7	30.4	4.8	32.3	2.7	33.2	2.2	30.7	2.1
NSTX Collaborators	*4.3*	*4.8*	*0.2*	*4.8*	*0.3*	*5.1*	*0.3*	*5.1*	*0.4*	*5.2*	*0.5*
ARIES	0.3	0.1	0.2	0.1	0.2	0.2		0.2		0.2	
NSO/Econ Studies/APEX	1.0		1.1		1.1						
NCSX[2]	9.4	14.9	0.4	20.5		19.4		22.8		24.2	
NCSX Collaborators	*2.2*	*1.8*	*0.2*	*1.7*		*3.2*		*4.7*		*6.1*	
QPS (PPPL)	0.3	0.3	0.4	0.3	2.4	1.1		0.5		0.5	
CDX-U	0.7	0.8		0.8		0.7		0.8		0.8	
MRX/NSF Center	0.6	1.0		1.0		1.0		1.0		1.0	
NSF Collaboration –MRI	0.2		0.2		0.2		0.2		0.2		0.2
Heavy Ion Fusion	1.1	1.1	1.0	1.1	1.7	1.3	2.3	1.4	2.4	1.6	2.5
Magnetic Nozzle (MNX)	0.2	0.2		0.2		0.2		0.2		0.2	
FRC Rot. Mg. Fields	0.3	0.3		0.3		0.2	0.6	0.2	0.6	0.3	0.7
Plasma Applications & Basic Phys.	0.8	0.8		0.8		0.9	0.5	0.9	0.5	0.9	0.5
Diagnostics (incl ECE/3D Imgng)	0.5	0.5		0.5		0.5		0.6		0.6	
Theory	4.4	4.5	0.4	4.5	0.4	5.0	0.8	5.2	0.9	5.4	1.0
CPPG & Adv. Scientific Comp.	2.2	2.2	0.3	2.2	0.6	2.4	0.5	2.5	0.5	2.6	0.6
FRC Theory	0.2	0.2	0.1	0.2	0.1	0.3		0.3		0.3	
Science Education	0.6	0.6	0.1	0.6	0.1	0.7		0.7		0.7	
Off-Site Research											
Off-Site Univ.	0.8	0.8	0.1	0.8	0.1	0.9	0.3	0.9	0.3	0.9	0.3
Off-Site Res. (US)	6.7	6.5	1.5	6.5	2.0	7.1	1.5	7.3	1.5	7.6	1.5
Off-Site Res. (Int'l)	3.1	1.7	1.7	1.7	1.7	2.1	1.4	2.2	1.4	2.3	1.4
New Initiatives											
NSST					1.0		2.0		3.5		5.0
PCD Effect (ICC)			0.3		0.3		0.4				
Lithium Tokamak Experiment			0.7		0.6	0.6		0.6		0.6	
ITER (PPPL)	0.1	0.5	0.4	0.5	1.6	2.5		3.6		4.5	
ITER (flow through)	*0.4*	*1.5*		*1.5*	*5.4*	*13.2*		*30.7*		*50.9*	
PPPL ATFES Research Subtot	**59.4**	**67.4**	**12.5**	**73.0**	**18.8**	**79.5**	**13.2**	**85.1**	**14.0**	**85.9**	**15.8**
Facilities											
D-Site Caretaking	0.5	0.5		0.5		0.6		0.6		0.6	
GPP	1.3	1.4		1.4	0.2	1.6		1.7		2.3	
Indirect Capital Equipment	0.1	0.1		0.1		0.1		0.1		0.1	
Facilities ***Subtotal***	***1.9***	***2.0***		***2.0***	***0.2***	***2.3***		***2.4***		***3.0***	
AT PPPL Fusion Energy Sciences	**61.3**	**69.4**	**12.5**	**75.0**	**19.0**	**81.7**	**13.2**	**87.5**	**14.0**	**88.9**	**15.8**
AT – PPPL + Exper. Collaborators	*67.7*	*76.0*	*12.9*	*81.5*	*19.3*	*90.0*	*13.5*	*97.3*	*14.4*	*100.2*	*16.3*
Non-AT											
FS/GD- Safeguards & Security	**1.8**	**1.8**		**1.8**		**1.9**		**1.9**		**2.0**	
KJ - Adv. Sci. Comp. Research	**0.4**	**0.4**		**0.4**		**0.4**	**7.0**	**0.4**	**7.0**	**0.4**	**7.0**
KA - High Energy Physics	**0.2**	**0.2**	**0.1**	**0.2**	**0.1**	**0.2**		**0.2**		**0.3**	
KG – Science Lab Infrastr.	**0.5**	**1.0**		**8.8**		**2.0**		**2.0**		**2.0**	
KX /KL- ERULF/SULI	**0.2**	**0.2**		**0.2**		**0.1**		**0.1**			
Non DOE Work for Others	1.8	2.0		2.0		2.0		2.0		2.0	
Non - AT Total	**4.9**	**5.6**	**0.1**	**13.4**	**0.1**	**6.6**	**7.0**	**6.6**	**7.0**	**6.7**	**7.0**
PPPL Funding Total	**66.2**	**75.0**	**12.6**	**88.4**	**19.1**	**88.3**	**20.2**	**94.0**	**21.4**	**95.6**	**22.8**

1. Reflects May 2003 AFP
2. MIE @ 73.5 as shown in PEP and OMB-300 Plus Research Preparations

Table 4. Laboratory Personnel Summary

AT-Fusion Energy Sciences	FY03(2	FY04		FY05		FY06		FY07		FY08	
	Base	Base	Incr.	Base	Incr.	Base	Incr.	Base	Incr.	Base	Incr.
On-site Research											
NSTX (PPPL)	116.6	123.6	5.9	118.8	6.6	120.3	4.0	119.8	1.4	103.1	
ARIES	1.0	0.3	0.4	0.3	0.4	0.5		0.5		0.5	
NSO/Econ Studies/APEX	2.4		3.2		3.1						
NCSX(3)	30.0	35.9		39.4		69.3		64.7		68.1	
QPS (PPPL)	1.0	0.3	0.8	0.5	1.5	0.7		1.1		1.1	
CDX-U	2.9	2.7		2.7		2.7		2.7		2.7	
MRX/NSF Center	3.3	4.5		4.5		4.5		4.5		4.5	
NSF Collaboration - MRI	1.1		1.1		1.1		1.1		1.1		1.1
Heavy Ion Fusion	5.1	4.6	4.1	4.7	6.4	5.2	8.3	5.4	8.3	5.9	8.3
Magnetic Nozzle (MNX)	1.4	1.4		1.5		1.4		1.4		1.4	
FRC Rot Mag. Fields	1.6	1.6		1.6		1.2	3.3	1.1	3.0	1.4	3.3
Plasma Applications & Basic Physics	4.4	3.5		3.5		3.4	1.6	3.4	1.6	3.4	1.5
Diagnostics (incl ECE/3D Imgng)	1.6	1.4		1.3		1.3		1.3		1.3	
Theory	16.5	16.9	1.0	16.7	1.2	17.8	2.3	17.7	2.3	17.6	2.3
CPPG & Adv. Scientific Comp.	8.5	8.4	1.2	7.8	2.5	8.0	2.5	8.0	2.5	8.0	2.5
FRC Theory	1.0	0.7	0.6	0.7	0.6	1.0		1.0		1.0	
Science Education	3.1	2.6		2.6		2.6		2.6		2.6	
Off-Site Research											
Off-Site Univ.	2.4	2.6	0.4	2.6	0.4	2.7	1.1	2.9	1.0	2.7	1.0
Off-Site Res. (US)	23.0	22.3	4.2	21.5	4.4	21.6	3.6	21.6	3.6	21.5	3.6
Off-Site Res. (Int'l)	12.1	5.0	5.5	5.0	5.3	5.8	4.1	5.9	3.8	5.9	3.6
New Initiatives											
NSST					4.0		7.7		10.5		14.0
PCD Effect (ICC)			1.7		1.9		1.9				
Lithium Tokamak Experiment			4.0		3.9	3.7		3.5		3.4	
ITER (PPPL)	0.9	1.8	1.5	1.6	5.1	7.7		11.4		14.0	
PPPL AT FES Research Subtotal	240.5	240.7	35.7	237.7	48.4	281.3	41.5	280.5	39.0	270.0	41.2
Facilities											
D-Site Caretaking	1.9	1.9		1.9		1.9		1.9		1.9	
GPP	1.0	1.0		1.0		1.0		1.0		1.0	
Subtotal	2.9	2.9		2.9		2.9		2.9		2.9	
AT-PPPL Fusion Energy Sciences[2]	243.5	243.6	35.7	240.6	48.4	284.2	41.5	283.4	39.0	272.9	41.2
FSGD- Safeguards & Security	18.4	18.4		17.2		17.0		16.2		16.7	
KJ – Office of Comp. & Tech Res.	1.9	1.9		1.9		1.9	7.0	1.8	6.5	1.7	3.0
KA - High Energy Physics	1.2	1.2	0.6	1.2	0.6	1.2		1.1		1.6	
KH-Excess Facilities Disposition	4.0	6.0		11.0		10.0		10.0		10.0	
KX/KL ERULF/SULI											
Non DOE Work for Other	12.0	9.0		10.8		10.3		9.9		9.5	
Non – AT Total	37.5	36.5	0.6	42.2	0.6	40.4	7.0	39.1	6.5	39.5	3.0
Indirect Technical Staff[4]	20.0	19.0		19.0		19.0		19.0		19.0	
Total Direct Personnel	301.0	299.1	36.3	301.8	49.0	343.6	48.5	341.5	45.5	331.5	44.2
Total Indirect Personnel (G&A)	154.0	154.0	6.0	160.0	9.0	165.0	9.0	168.0	10.0	165.0	10.0
Total FTE's	455.0	453.1	42.3	461.8	58.0	508.6	57.5	509.5	55.5	496.5	54.2
Less subcontract & term employees[1]	5.0	6.1	42.3	11.8	58.0	59.6	57.5	60.5	55.5	47.5	54.2
Less Graduate students	31.0	28.0		31.0	30.0	30.0		30.0		30.0	
PPPL Staff	419.0	419.0		419.0		419.0		419.0		419.0	

1. Includes PPPL hired and supervised subcontractors
2. Includes direct allocations (cc54xx)
3. CDR May 2002
4. Technical Staff performing technical functions but charged indirectly (cc51, 52, 53, 54, 55xx)

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

Current Year $M – BA	FY03	FY04	FY05	FY06	FY07	FY08
Office of Science						
Operating	60.0	68.0	73.6	80.1	85.8	86.6
Capital Equipment						
General Plant Projects (GPP)	1.3	1.4	1.4	4.6	1.7	2.3
Total	**61.3**	**69.4**	**75.0**	**81.7**	**87.5**	**88.9**
FS/GD – Safeguards & Security	1.8	1.8	1.8	1.9	1.9	2.0
KJ – Adv. Sci. Comp. Research	0.4	0.4	0.4	0.4	0.4	0.4
KH – Excess Facilities Disposition	0.5	1.0	8.8	2.0	2.0	2.0
KA - High Energy Physics	0.2	0.2	0.2	0.2	0.2	0.3
KX/KL – ERULF/SULI	0.2	0.2	0.2	0.1	0.1	
Non DOE Work for Others	1.8	2.0	2.0	2.0	2.0	2.0
Total Laboratory Funding (w/o collaborator funding)	**66.2**	**75.0**	**88.4**	**88.3**	**94.0**	**95.6**

Table 6. Collaborator Funding for National Projects

AT-Fusion Energy Sciences	FY03	FY04	FY05	FY06	FY07	FY08
NSTX	4.3	4.8	4.8	5.1	5.1	5.2
NCSX	2.2	1.8	1.7	3.2	4.7	6.1
Total	**6.5**	**6.6**	**6.5**	**8.3**	**9.8**	**11.3**

Table 7. Laboratory Staff Composition

	Ph.D.		MS/MA		BS/BA		Other		Total	
	No.	%	No.	%	No.	%	No.	%	No.	%
Professional Scientist	94	22.4	0	0	0	0	1	0.2	95	22.6
Professional Engineer	15	3.6	29	6.9	32	7.6	4	1.0	80	19.0
Management & Administrative	3	0.7	21	5.0	23	5.5	27	6.4	74	17.6
Support/ Technician	0	0	0	0	13	3.1	141	33.6	154	36.7
All Other	0	0	1	0.2	0	0	16	3.8	17	4.0
Totals	112	26.7	51	12.1	68	16.2	189	45.0	420	100

(May 2003)

Table 8. Experimenters at Designated User Facilities FY02

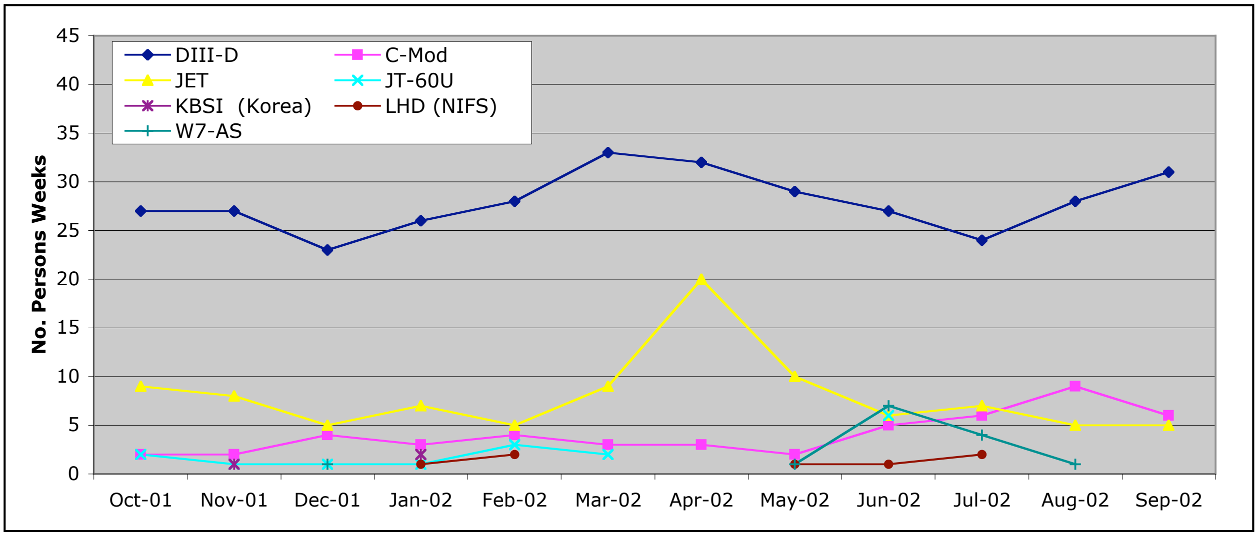


Table 9. Laboratory Space Distribution

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	FY03	FY04	FY05-07
Safety	500	700	2,100
Improvement	500	500	2,600
Environment	3000	200	0
Security	1,600	0	0
TOTAL	2,900	1,400	4,700

Table 12. Equal Employment Opportunity

	Officials/ Managers	Scientists & Engineers	Technicians	All Other	Total	
	No.	No.	No.	No.	No.	%
Minority						
Males	1	31	10	3	45	12.8
Females	1	2	1	11	15	21.7
White						
Males	49	112	110	36	307	87.5
Females	6	6	4	37	53	76.8
Black						
Males	0	2	7	2	11	3.1
Females	0	0	1	9	10	14.5
Hispanic						
Males	0	0	0	1	1	0.3
Females	0	1	0	2	3	4.3
Native American						
Males	0	0	2	0	2	0.6
Females	0	0	0	0	0	0.0
Asian/Pacific Islander						
Males	1	29	0	0	30	8.5
Females	1	1	0	1	3	4.3
Total						
Males	50	143	119	39	351	83.6
Females	7	8	5	49	69	16.4

(May 2003)

Table 13. Completed Dissertations for 2002 – 2003

Jones, Brent, "Electron Bernstein Wave Thermal Emission and Mode Conversion in the CDX-U Spherical Torus," November 2002, Advisors: Philip Efthimion and Gary Taylor.

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

Zaharia, Sorin, "3-D Magnetospheric Structures and Energetic Particle Injections," June 2003, Advisor: C. Z. (Frank) Cheng.

(listing as of 6/30/03)

Table 14. Overview of NSTX Research Program

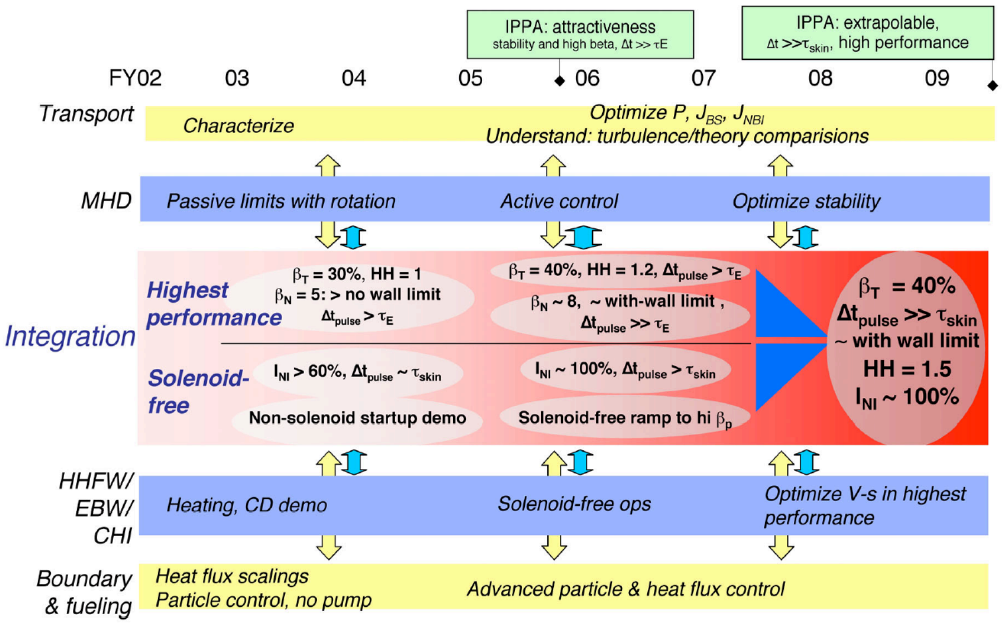


Figure 1. Condition of Laboratory Space

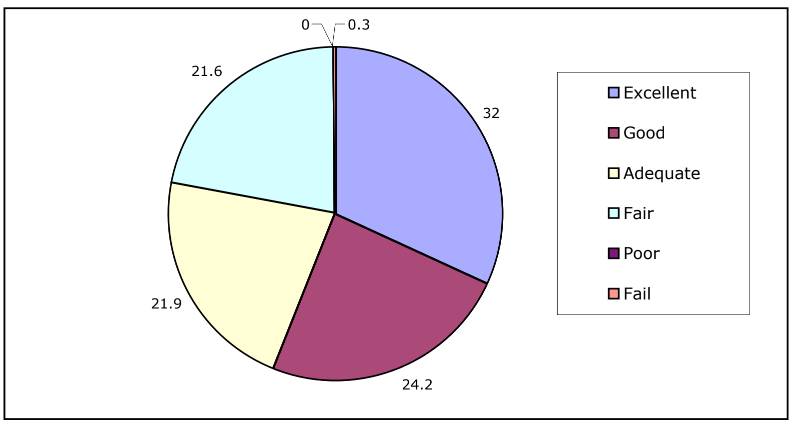


Figure 2. Use and Condition of Laboratory Space

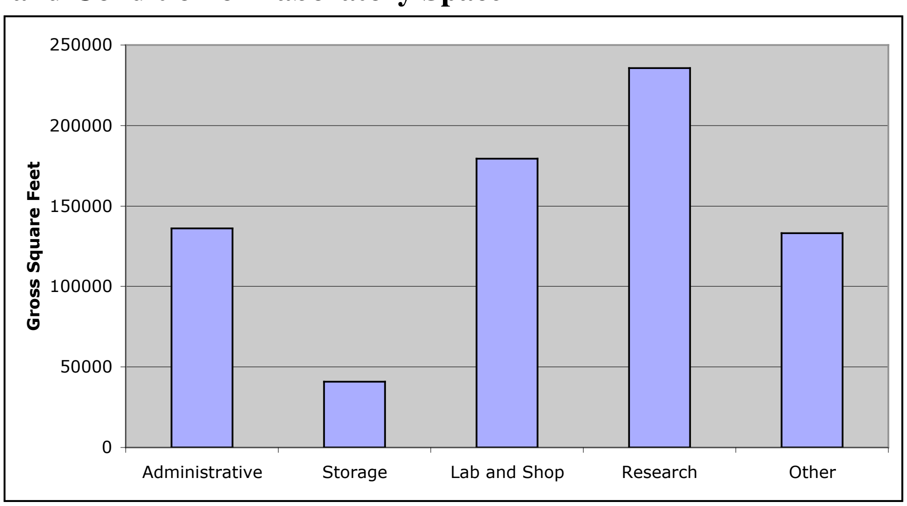
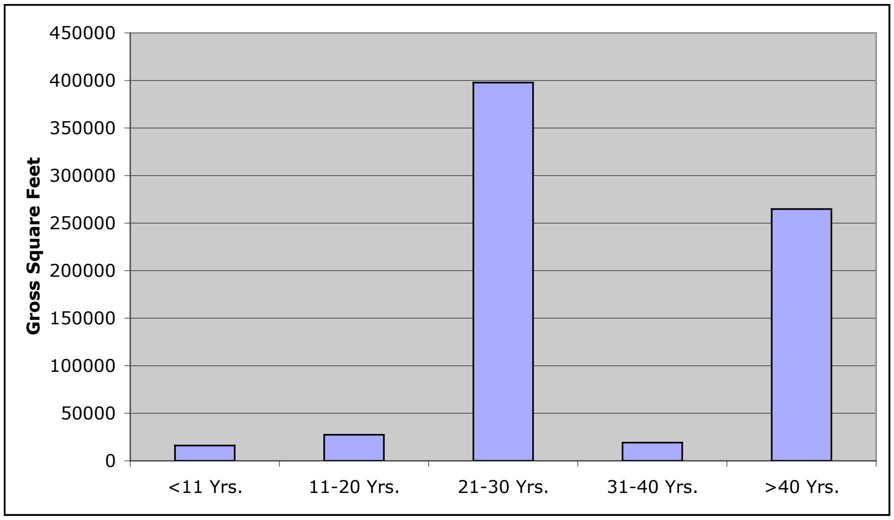


Figure 3. Age of Laboratory Buildings



Acronyms

ALPS	Advanced Liquid Plasma-facing Surface
ARIES	Advanced Reactor Innovation Evaluation Study
AT	Advanced Tokamak
BES	Basic Energy Sciences
CAMP	Capital Asset Management Process
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
CTF	Component Test Facility
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
EFDA	Europeian Fusion Development Agreement
ES&H	Environment, Safety and Health
ES&H/IS	Environment, Safety and Health and Infrastructure Support Department
FESAC	Fusion Energy Sciences Advisory Committee
FIRE	Fusion Ignition Research Experiment
FLC	Federal Laboratory Consortium
FRC	Field Reversed Configuration
FY	Fiscal Year
GPP	General Plant Projects
HBT-EP	Experiment at Columbia
HHFW	High Harmonic Fast Wave
HIT	Helicity Injected Tokamak
HIT-II	Experiment at University of Washington
ICRF	Ion Cyclotron Range of Frequencies
IFE	Inertial Fusion Energy
ISM	Integrated Safety Management
ITER	International Burning Plasma Experiment
JET	Joint European Torus (Experimental fusion facility in England)
JT-60U	Experimental fusion facility in Japan
KSTAR	Korea Superconducting Tokamak Research Project
kW	Kilo-watt
kWh	Kilo-watt hour
LHD	Large Helical Device
LTX	Lithium Tokamak Experiment
LLNL	Lawrence Livermore National Laboratory
LPDA	Laboratory Program Development Activities
LSB	Lyman Spitzer Building
MAST	Experiment at Culham, England
MFE	Magnetic Fusion Energy
MHD	Magnetohydrodynamics
MIT	Massachusetts Institute of Technology
MNX	Magnetic Nozzle Experiment
MRI	Magnetorotational Instability
MRX	Magnetic Reconnection Experiment
MSE	Motional Stark Effect
NASA	National Aeronautics and Space Administration
NBI	Neutral Beam Injection

NCSX	National Compact Stellarator Experiment
NERSC	National Energy Research Scientific Computing
NRC	Nuclear Regulatory Commission
NSF	National Science Foundation
NSST	Next Step Spherical Torus
NSTX	National Spherical Torus Experiment
OFES	Office of Fusion Energy Sciences (DOE)
ORNL	Oak Ridge National Laboratory
OSHA	Occupational Safety and Health Administration
PAC	Program Advisory Committee
PDC	Ponderomotive Current Drive
PBX-M	Princeton Beta Experiment-Modification
PPPL	Princeton Plasma Physics Laboratory
PSACI	Plasma Science Advanced Computing Initiative
PS&T	Plasma Science and Technology Department
QA	Quasi-axisymmetry
QAS	Quasi-axisymmetry Stellarator Concept
QP	Quasi-polodial
QPS	Quasi-Polodial Stellarator
R&D	Research and development
RF	Radio-frequency
RMF	Rotating Magnetic Field
SC	Office of Science (DOE)
SciDAC	Scientific Discovery through Advanced Computing
SF	Square Foot
SLI	Science Laboratory Infrastructure Program
SOL	Scrape of layer
ST	Spherical torus
T	Tesla (a unit of magnetic strength)
TCF	Topical Computing Facility
TFTR	Tokamak Fusion Test Reactor
TRC	Technical Resources Committee
U.K.	United Kingdom
US	United States
VNL	Heavy Ion Fusion Virtual National Laboratory
WFO	Work-for-Others