INTRODUCTION

The PPPL Theory Department plays a leading role in helping the Fusion Energy Science program achieve improved scientific understanding of the physics of plasmas and fusion devices. Improvements in theoretical and computational tools, as well as improved plasma diagnostics, have made possible much more comprehensive comparisons of experimental results from the leading confinement devices with detailed theoretical models that have been developed, and will continue to be developed, in the Theory Department. The modern, international research environment is continually changing, in large part because of the ever-increasing capabilities of computing architectures. The Theory Department is the premier theoretical plasma physics group and must continually adapt to such changes in the research environment. This has advanced scientific understanding dramatically and has stimulated the development of new concepts and of innovative methods for improving performance. The Theory Department maintains extensive domestic and international collaborations that both synergistically enhances research across a broad spectrum of plasma physics and ensures that the PPPL Theory Department, in association with the Department of Astrophysical Sciences of Princeton University, will remain at the forefront of research for the next generation. Researchers in the Theory Department also play a vital role in the graduate education of young plasma physicists via its participation in Princeton University's Department of Astrophysical Science. They are also engaged in the transfer of knowledge and methodology developed in the mainline fusion area to investigate alternative paths to fusion energy and to non-fusion plasma applications.

RESPONSIBILITIES

Theoretical activity at PPPL involves (i) providing fundamental conceptual foundations and innovative new scientific ideas for plasma theory; (ii) development of the best theoretical and computational tools to enable strong scientifically-based interpretation and extrapolation of experimental observations; and (iii) application of advanced modeling capabilities for the analysis of existing experiments and the design of future devices. The fundamental studies of the properties of plasma form a base for the applied studies to build upon, and also provide recognition and a chance to interact and share ideas with scientists in other related disciplines. The more applied theoretical studies provide the tools for interpreting data from experiments, and also for developing new fusion and non-fusion plasma concepts. PPPL maintains strong theoretical programs in each of the following areas:

Fundamental Plasma Theory:

- Developing the fundamental theory and computational capabilities to enable better scientific understanding of plasma turbulence
- Developing new representations and theoretical closures to enable more realistic and efficient computation of the nonlinear macroscopic properties of plasmas

- Developing the hybrid-theoretical tools, kinetic and macroscopic, needed to address energetic particle physics of particular importance to burning plasmas
- Develop the theory and computational tools to enable a fundamental understanding of scientific issues intrinsic to three-dimensional magnetic confinement configurations

Tokamak Theory:

- Developing advanced gyrokinetic and continuum (Vlasov) models for simulating transport dynamics
- Utilizing the increasingly powerful massively parallel computational resources effectively to accelerate the development and application of new modeling tools
- Validating new models with higher physics fidelity against both analytic theory and experimental observations
- Enhancing progress in tokamak theory via a better physics understanding of features: as particle, energy and momentum transport; barrier formation; blob dynamics; and active stabilization of the most dangerous macroscopic modes
- Investigating certain critical burning plasma issues, such as conditions for the onset of energetic particle driven MHD modes and their possible impact on the confinement properties of burning plasmas

Alternate Confinement Configurations:

- Providing insights into the scientific interpretation of experimental results from the National Spherical Torus Experiment at PPPL, the low-aspect-ratio limit of the tokamak
- Providing the theoretical and computational tools for supporting W7X and LHD, the recently constructed stellarator in Germany and the stellarator in Japan
- Providing theoretical and modeling support for experiments on the Field Reversed Configuration (FRC), heavy ion fusion, high energy density physics, and laser/plasma interaction, and other alternate confinement areas.

Non-Fusion Applied Plasma Theory:

- Theoretical plasma physics applications to space plasmas include mode conversion, kinetic alfven waves, and associated plasma transport and stability analysis.
- Investigate other applications, such as, as non-neutral plasmas, collective processes in intense charged particle beams, plasma thrusters, laser/plasma interactions, etc.

Computational Plasma Physics Science:

- Fostering the extension and development of modern computational analysis in support of fusion science research with both community leadership activities such as the Plasma Science Advanced Computing Initiative and participation in national research efforts such as DOE's Scientific Discovery through Advanced Computing (SciDAC) program, which targets deployment of advanced computing capabilities to solve scientific problems of extraordinary complexity.
- In collaboration with the Computational Plasma Physics Group (CPPG), streamlining, modernizing, and extending existing 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
- Participating with the CPPG in research activities such as the Fusion Energy Science Collaboratory Project to 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

(foreign) tokamaks, and extending these methods and standards to stellarators and/or other alternate concept magnetic confinement devices;

- Supporting the worldwide use and analysis of TRANSP, an essential transport modeling code, and other major numerical codes.
- Developing major PPPL simulation codes by facilitating their implementation on parallel computers, while extending their physics and improving their user interface and visualization capabilities in conjunction with CPPG