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. This has advanced scientific understanding dramatically and has stimulated the development of new concepts and of innovative methods for improving performance. 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 also 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 (kinetic and macroscopic) theoretical tools needed to address energetic particle physics of particular importance to burning plasmas.
- developing the theoretical and modeling capabilities to provide scientific insights into magnetic reconnection dynamics in laboratory as well as natural plasma environments.

Tokamak Theory:

- develop advanced gyrokinetic and continuum (Vlasov) models for simulating transport dynamics utilization of powerful
- effectively utilize the increasingly powerful massively parallel computational resources to accelerate the development and application of new modeling tools
- validate new models with higher physics fidelity against both analytic theory and experimental observations
- enhancing progress in tokamak theory via developing a better physics understanding of such features as the conditions for transport barrier formation and for the active stabilization of the most dangerous macroscopic modes leading to disruptions;
- 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:

- Provide insights into the scientific interpretation of experimental results from the National Spherical Torus Experiment at PPPL, the low-aspect-ratio limit of the tokamak;
- Provide the theoretical foundations for the design and further improvement of the stability and confinement properties if quasi-axisymmetric (QA) stellarator configurations;
- conduct exploratory studies related to the Field Reversed Configuration (FRC), inertial fusion energy (IFE), and laser/plasma interaction, and other alternate confinement areas.

Non-Fusion Applied Plasma Theory:

- Develop a miniature nuclear detector system in support of homeland security.
- Interpret the wealth of data developing from space plasma physics impacting areas such as wireless communication technology.
- Investigate other applications, such as plasma thrusters, laser/plasma interactions.

Computational Plasma Physics Science:

- Foster 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 Institute and active 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;
- Participate 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;
- Work closely with the CPPG in the development of major PPPL simulation codes by facilitating their implementation on parallel computers, while extending their physics and improving their user interface and visualization capabilities.