Weekly HIGHLIGHTS

PPPL PRINCETON PLASMA PHYSICS LABORATORY

U.S. DEPARTMENT OF ENERGY

The PPPL Highlights for the week ending November 18, 2016 are as follows:

U.S. ITER FABRICATION (C. NEUMEYER):

Steady State Electric Network (SSEN):

This week the SSEN and Diagnostics Engineering teams participated in the US ITER Independent Project Review (IPR) at the US ITER offices in Oak Ridge, Tennessee. The purpose of the IPR was to achieve CD-2 and CD-3 project certification from the DOE. For SSEN, which is almost complete with all procurement and ITER deliveries, a CD-3 designation was achieved. Diagnostic engineering design completion projects achieved CD-2 while the small portion of diagnostic first plasma hardware obligations were designated CD-3. This is a major step for the US ITER project and sets a performance baseline for the ITER engineering work at PPPL.

Diagnostics:

Diagnostics and Port Plug Engineering; EP09 The TIP optics cassette (EP9 DSM3) has undergone final refinements for cooling over concerns with a localized hot-spot. Thermal analysis for that region is now in work to verify design. Also, design studies are in progress for modification of uncooled mirror mounts for improved RH access.

The ECE Hot Source assembly (EP9 DSM2) is now fully rendered in CATIA and will soon be drafted into ENOVIA updates. This provides a basis for neutronics modeling (also in work) and refines the Port Plug assembly weight estimates.

ECE: PPPL is performing bakeout tests of the prototype piezo motor that is a candidate actuator for the ECE shutter-mirrors. The piezo-motor prototype survived 72 hours at 200C bakeout in vacuum and performed 10 cycles at 100C. Another two bakeout cycles are in process now. Performance in the unsteady magnetic field environment will also be tested. Also this week, a revised design of the ECE front optics fixed mirrors was created by the PPPL ECE engineering team. The new design uses the same principal of attachment and alignment as the TIP system mirror design. At the University of Texas the hot calibration source engineering team is testing the performance of the new Molybdenum heater. A new CATIA CAD model of the latest hot calibration source with the molybdenum heater was created and delivered to PPPL so it can be used in the upcoming EP9 neutronics analysis.

Jorge Teodoro is a new member of the ITER diagnostics engineering staff. He previously worked at the ITER site in France in the machine integration group.

NSTX-U (M. ONO):

Steve Sabbagh and Jack Berkery of Columbia University attended the MHD Stability and Control Workshop held at General Atomics in San Diego, CA (November 7-9), giving the lead (invited) and second talks of the meeting, respectively titled "Disruption Event Characterization and Forecasting in Tokamaks", and "Resistive Wall Modes Stability Physics and Forecasting in NSTX and NSTX-U.

R. Kaita (PPPL) gave a presentation entitled "Student Research Opportunities at National Laboratories" at the Annual Meeting of Sigma Xi, The Scientific Research Society. Recent research conducted at PPPL under the USDOE Student Undergraduate Laboratory Internship (SULI) program was highlighted, including projects related to NSTX-U. He was also a member of a panel on the topic "Putting your Degree to Work: Career Options for STEM Graduates." The panelists represented academia, government, and industry, and provided ideas and resources for pursuing careers in each of these areas.

J. Menard (PPPL) traveled to Cadarache, France on November 15-17, to serve as a reviewer for the Preliminary Design Review of the ITER Plasma Control System.

The center column (center-stack) was removed from NSTX-U this past week, and is being prepared for metrology and disassembly.

ITER & TOKAMAKS (R. HAWRYLUK):

R. Hawryluk attended the IAEA DEMO Programme Workshop in Karlsruhe. He gave a talk on "H-mode Core Plasma Confinement", which focused on three general topics: uncertainty in zero dimensional scaling relations; going beyond scaling relationships; and new operating modes and what is required to establish them.

DIII-D (R. Nazikian)

B. Grierson, N. Logan and S. Haskey attended the OMFIT developers "Code Camp" this week to focus on improving existing physics modules and developing new capabilities for emerging analysis needs. This opportunity was used to improve the algorithms for aligning the plasma profiles (Te, Er) to the separatrix for accurate edge equilibrium reconstruction and stability analysis, develop a tutorial for kinetic equilibrium reconstruction on NSTX, and implement goodness of fit statistics for the profile fitting packages provided by the OMFIT framework.

Recent CER measurements of the main-ion temperature in the steep gradient region of the H-mode pedestal indicate that the deuterium temperate can be considerably lower than the impurity temperature at the separatrix (Haskey APS-DPP 2016). This results in a higher ion temperature gradient than inferred from impurity measurements. Pedestal stability analysis using the ELITE code demonstrates that the peeling boundary can be significantly affected. This result has implications for pedestal stability analysis when significant differences between main-ion and

impurity temperature gradients are present. Further work will quantify the differences in stability at high and low pedestal collisionality.

R. Maingi visited DIII-D to discuss boundary physics activities, to discuss gyrokinetic analysis of DIII-D lithium dropper discharges, and to discuss proposals for the NSTX-U campaign on DIII-D. Also, a video conference was held with the EAST team and DIII-D members to plan the upcoming lithium experiments on EAST.

International Collaborations and ITER:

F. Poli visited ASIPP from November 8 to November 18 to work with the EAST team on TRANSP simulations of discharges with LHCD. She has worked with TRANSP users on the implementation of the GENRAY+CQL3D loop for use with the two frequency antennae on EAST and on the capability of submitting TRANSP runs to the fusiongrid from their system.

Tim Stevenson participated in a JET Ad Hoc Committee Technical review at CCFE, Culham UK from November 16-18. The committee reviewed the JET technical status and extensive plans for upcoming work to prepare for a protracted experimental campaign using hydrogen, deuterium, and eventually tritium if approved. The plans for both the outage and the new work needed to support expected experiments are very well formulated. The close out and exit meeting was held with the JET Team and included Drs. Jerome Pamela and Tony Dunne participating remotely. The committee will submit their written report by the end of the calendar year.

ADVANCED PROJECTS (H. NEILSON):

C. Kessel, Y. Zhai, and H. Neilson attended the IAEA DEMO Programme Workshop at Germany's Karlsruhe Institute of Technology this week. Kessel gave a special session presentation on the "FNSF, Its Motivation and Program to Develop a Basis for Power Plants" to an international group of physicists and engineers. The importance of a smaller intermediate step toward a DEMO and a power plant was described and can be contrasted with the numerous large DEMO proposals being made to immediately follow ITER. The areas covered included the overall view of a fusion nuclear science facility (FNSF) in the development pathway to power plants, discussion of preparing for and taking the first fusion nuclear step, missions and metrics for the facility, the complexities of the fusion core environment and uniqueness of the facility to provide them, the program on the FNSF, fusion core components and the strategies for using them to establish a new database for the DEMO and power plants, and a discussion of the primary thrusts of a pre-FNSF R&D program. Zhai made a poster presentation, "High Performance Superconductors for the Next Step Fusion Reactors," discussing high performance superconductor options and winding pack stress analysis for the FNSF toroidal field magnet system. High-Tc superconductor options for the FNSF and for spherical tokamak and stellarator applications were also examined. Neilson attended as a member of the workshop's technical program committee.

S. Lazerson was appointed to a Task Force leadership position for the upcoming Wendelstein 7-X (W7-X) experimental campaign, known as OP1.2. The Scenario Development task force, which Dr. Lazerson will head, will prioritize experimental proposals and develop a plan for the OP1.2 campaign. The major goal of this task force is to demonstrate capabilities which will be

necessary to achieve both high-beta and long pulse operation when the fully cooled divertor is installed in the subsequent campaign, known as OP2.

THEORY (A. BHATTACHARJEE):

On November 14, Fabio Riva (EPFL, Switzerland) presented a Theory Seminar on the development and applications of verification and validation (V&V) procedures. V&V is composed by three separate tasks: (i) *code* verification, a mathematical procedure ascertaining if the physical model is correctly implemented; (ii) the *solution* verification, which quantifies the numerical errors; and (iii) the *validation*, which determines the consistency of the results with experimental data. The method of "manufactured solutions" has been generalized to particle-in-cell (PIC) codes, thereby overcoming the difficulties of intrinsic statistical noise. The solution verification procedure is based on Richardson extrapolation. These verification procedures were applied to GBS, a three-dimensional fluid code for scrape-of-layer (SOL) plasma turbulence simulations, and to a unidimensional, electrostatic, collisionless PIC code. The magnetic geometry of the simulation code was generalized to include elongation and non-zero triangularity, and the plasma shaping effects on SOL turbulence were investigated. An experimental campaign is now planned on TCV to validate the findings against experimental measurements in tokamak limited configurations.

On November 17, Michael Kraus (Max Planck Institute for Plasma Physics, Garching) presented a Theory Seminar on degenerate-Lagrangians, noncanonical Hamiltonians, Dirac constraints and their discretizations. Most systems encountered in plasma physics are Hamiltonian and therefore have a rich geometric structure, most importantly *symplecticity* and conservation of momentum. These systems are often formulated in non-canonical coordinates, and so they are not amenable to standard symplectic discretisation methods, which are popular for the integration of canonical Hamiltonian systems. Variational integrators, the Lagrangian equivalent to symplectic methods, provide an alternative structure-preserving numerical method for such systems. However, for non-canonical Hamiltonian systems, the Lagrangian is often degenerate and this causes instabilities of the variational integrators that need to be overcome in order to make long-time simulations possible. Recent attempts to devise long-time stable structure-preserving integrators for non-canonical Hamiltonian and degenerate-Lagrangian systems were reviewed. The guiding-center system was used to exemplify the problems that arise for such systems, and to demonstrate the good, long-time fidelity of the newly developed integrators.

On November 18, Pavel Lushnikov (U New Mexico) presented a Theory Seminar on optical collapse and nonlinear laser beam combining. Many nonlinear systems of partial differential equations admit spontaneous formation of singularities in a finite time (blow up). Blow up is often accompanied by a dramatic contraction of the spatial extent of solution, which is called by collapse. A collapse in a nonlinear Schrodinger equation (NLSE) describes the self-focusing of the intense laser beam in the nonlinear Kerr medium (like usual glass) with the propagation distance z playing the role of time. The NLSE in two dimensions (two transverse coordinates) corresponds to the stationary, self-focusing of the laser beam and eventually causes optical damage, as was routinely observed in experiments since the 1960s. The NLSE in three dimensions (two transverse coordinates and time) is responsible for the formation of the "optical bullet", making the pulse much shorter in time, in addition to the spatial self-focusing. The universal, self-similar scaling near the collapse was addressed. In the critical 2D case, the

collapsing solutions have a form of rescaled soliton such that the z-dependence of that scale determines the z-dependent collapse width $L(z)$ and amplitude $\sim 1/L(z)$. At the leading order $L(z) \sim (z_c - z)^{1/2}$, where z_c is the collapse time with the required log-log modification of that scaling. A new asymptotic theory was developed that is valid starting from quite moderate (about 3 fold) increase of the solution amplitude compared with the initial conditions. A nonlinear combining of multiple laser beams into a diffraction-limited beam by beam self-focusing in Kerr mediums was proposed. Multiple beams with total power above critical are combined in near field and propagated through multi-mode optical fiber. Random fluctuations during propagation first trigger the formation of the strong optical turbulence. During subsequent propagation, the inverse cascade of optical turbulence tends to increase the transverse spatial scale of fluctuation until it efficiently triggers a strong optical collapse event producing diffraction-limited beam with the critical power.

On November 18, I. Kaganovich presented a colloquium at the Worcester Polytechnic Institute in Worcester, MA, and gave colloquium to the Aerospace Department entitled "Kinetic Modeling of Plasma Discharges for Modern Applications". The purpose of the talk was to describe the recent advances in nonlocal electron kinetics in low-pressure plasmas. Low-pressure discharges are widely used in industry as the main plasma sources for many applications including plasma processing, discharge lighting, plasma propulsion, particle beam sources and nanotechnology. Being partially-ionized, bounded, and weakly-collisional, the plasmas in these discharges demonstrate nonlocal electron kinetic effects, nonlinear processes in the sheaths, beam-plasma interaction, collisionless electron heating, etc. Such plasmas often have a non-Maxwellian electron velocity distribution function. The plethora of kinetic processes supporting the non-equilibrium plasma state is an invaluable tool, which can be used to adjust plasma parameters to the specific needs of a particular plasma application. Recent advances in nonlocal electron kinetics in low-pressure plasmas were reported, where a non-Maxwellian electron velocity distribution function was "designed" for a specific purpose: in dc discharges with auxiliary biased electrodes for plasma control, hybrid DC/RF magnetized and unmagnetized plasma sources, and Hall thruster discharges. We show using specific examples that this progress was made possible by synergy between full-scale particle-in-cell simulations, analytical models, and experiments.

BUSINESS OPERATIONS (K. FISCHER):

K. Fischer attended the NLCFO meeting on November 16 - 17 at the National Renewable Energy Laboratory (NREL) in Golden, Colorado. CFOs from the DOE National Laboratories gather together to network and discuss relevant issues common to all. Topics covered during the meeting included DOE updates and Annual State of the Lab report, ICR Consistency Review Planning, Lease Accounting Rules and Implementation of New Technologies.

DIRECTOR'S OFFICE (C. AUSTIN):

On October 28, Lieutenant General Frank Klotz (Retired), Administrator of the United States Department of Energy's National Nuclear Security Administration, visited PPPL. PPPL leadership discussed research collaborations with NNSA and a tour was provided.

On October 31, D. McComas, S. Weidner, T. Brog, M. Zarnstorff and S. Zelick traveled to the U.S. Department of Energy's (DOE) HQ last week to meet with Dr. Cherry Murray, director of DOE's Office of Science, and other top leaders in that Office.

On November 9-10, PPPL leadership hosted the bi-annual PPPL Advisory Board meeting. The Advisory Board helps assess both the scientific and operations sides of the Lab.

On November 9, Dr. Wolfgang Schleich, "University of Ulm / Texas A&M University, presented a colloquium entitled, "History and Derivation of the Schrödinger Equation".

This report is also available on the following web site:
http://www.pppl.gov/publication-type/weekly-highlights