PRINCETON PLASMA PHYSICS LABORATORY
WEEKLY highlights

PPPL
U.S. DEPARTMENT OF ENERGY

The PPPL Highlights for the week ending January 8, 2016 are as follows:

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

Steady State Electric Network (SSEN):

On the Power Transformers procurement, a contract amendment was signed to cover changes that developed as result of the Release for Manufacturing design review process. A revised schedule was agreed to and manufacturing has started.

On the Uninterruptible Power Supply (UPS) system, DC Distribution, and Low Voltage (LV) Distribution and Sub-distribution Panels procurements, activities continued that will lead to a decision about the best strategy to pursue procurement of some of the items (battery banks associated with UPS and DC distribution, plus the LV Distribution and Sub-distribution Panels) that will likely be transferred to the ITER Organization (IO). They would be used for future procurement action to avoid long storage times (battery banks) and to allow more time for the load consumers' designs to evolve (LV panels).

Diagnostics:

Upper Wide Angle View VIS-IR Cameras (UWAVs): This week M. Smith completed a new electromagnetic finite element analysis (EM FEA) of the UWAVs in-vacuum components. R. Feder completed a new ATTILA neutronics analysis of UWAVs and Upper Port 14. The EM and nuclear loads will be used by the General Atomics based UWAVs engineering team to evaluate thermal and structural performance. Also this week, TNO started a critical analysis of the UWAVs Mirror Cleaning Prototype gas conductance to determine if sufficient partial pressure can be formed to create the mirror cleaning local Argon RF plasma.

Electron Cyclotron Emission (ECE): This week a working group formed to define ECE signals needed for real time control, in particular for Neoclassical Tearing Mode control. The group includes members from the US-DA, IN-DA and IO. The ECE and EP9 engineering team met this week to discuss the ECE Preliminary Design Review strategy and schedule. The new plan is to have two or three PDRs for various ECE components. The University of Texas ECE team needs to have a PDR focused just on the calibration hot source design sooner than the rest of the ECE system in order to retain some of their key personnel.

Toroidal Interferometer and Polarimeter (TIP): The TIP system relies on five corner cube reflectors (CCRs) embedded in vessel wall mounted blanket models. The thermal interface between these CCRs and the blanket modules is critical. While US ITER provides the TIP

system, the blankets are part of IO scope. PPPL has been working with the IO blanket group to design the CCR interface and this week PPPL received new FEA results from the IO. The analysis results show higher than expected temperature gradients at the base of a typical CCR, and the PPPL team will now need to show that this does not adversely effect the TIP optical performance.

Core Imaging X-Ray Spectrometer (CIXS): PPPL held a kick-off meeting with Dr. John Rice from MIT. Dr Rice will be working with the CIXS team on targeted system physics design issues and on laboratory testing of the x-ray crystals and detectors.

Port Plug Test Facility (PPTF): R. Feder met with Jeff Parrot to start working through logistics and cost estimates for bringing the very large port plug test facility to PPPL. Besides understanding costs, the PPPL team also wants to make sure transport is well planned and meets requirements of local and state road loads.

NSTX (M. ONO):

FY 2016 NSTX plasma operations update: The department has completed 1.26 run weeks and 116 plasma shots. The total operation targets are to be decided.

A press release has been published this week in Science Daily on the modeling of non-inductive ramp-up for NSTX-U by F. Poli (PPPL) and it can be accessed at http://www.sciencedaily.com/releases/2016/01/160105102214.htm.
The work highlighted in the release has been published recently in the Nuclear Fusion journal and shows the advantages of using electron cyclotron heating to increase the electron temperature and improve the absorption of High Harmonics Fast Waves (HHFW).

NSTX-U plasma operations resumed this week on January 4 after the first vacuum vessel boronization using the new deuterated trimethylboron (dTMB) injection system. Several Experimental Machine Proposals (XMP's) have since been performed to evaluate machine performance after boronization and have been successful in improving plasma elongation and vertical control, as well as optimizing OH pre-charge. Four of the neutral beam ion sources were qualified for experimental use with injections into in-vessel armor, and neutral beams were subsequently injected into NSTX-U plasmas for the first time since the upgrade. NSTX-U switched from helium to deuterium fueling to perform a calibration of neutron production during beam injection. The Plasma Control System (PCS) successfully demonstrated controlled plasma ramp-down for losses of plasma position control as well as the ability to turn-off the neutral beams. The PF1A coils were also used this week for diverted plasma operation, and the fast magnetics are recording a variety of MHD modes. While vacuum conditioning HHFW antennas, an electrical fault in RF Power Supply #5 damaged the Nichrome resistor assemblies of the crowbar circuit. The cause of the fault is being investigated, and repairs are being made. All six RF sources will remain off-line until work is complete. Also this week, a peer review of design concepts for the proposed new inner diverter tile thermal insulation was held.

A full bottle boronization was done on January 4. Data was also collected via XMP108 (TMB sequencing in support of XP1505) regarding coating thicknesses at various places in the machine via quartz microbalances. MAPP XPS measurements of surface composition showed the first

indications of carbon migration and boron oxidation.

Significant progress was made on XMP101 (Breakdown Optimization) on January 5 and 6. A stable and reproducible breakdown and current ramp scenario with an OH pre-charge of 8 kA has been developed. A 20 kA pre-charge scenario, capable of ultimately producing longer plasma pulses, has also been developed, though more tuning is required.

Significant progress was also made on XMP126 (Ip and R control) and XMP105 (Vertical Control Checkout) on January 6 and 8. Stable inner wall discharges with plasma currents of 500 kA were developed, with good plasma current and radial position control. These discharges were then elongated, and vertical control optimization started, using neutral beam heating on the second day. Different configurations of the vertical position observer were tested, as were different values of the vertical position control gains. Divertor coils were also used for the first time on January 8, resulting in further elongating of the plasma cross section. In general, vertical control proved challenging in these L-mode plasmas, and will continue to be a focus of attention.

A few discharges were also taken towards XMP132 (Automatic Discharge Shutdown Commissioning) on January 6. These commissioned the newly written PCS automatic disruption detector algorithm; loss of OH control (hitting the set limit), loss of vertical control, and loss of plasma current control were demonstrated to initiate a termination of the plasma discharge. Changes were successfully triggered in the plasma current controller, the plasma shape controller, and the vertical position controller.

Following the successful execution of an NBI operation procedure OP-NSTX-22 on January 6, XMP127 (Neutral Beam Checkout) was started on January 7. Individual shots with each of sources 1a, 1b, 1c, and 2c were taken, qualifying these for sources for subsequent plasma operations. This XMP will be revisited when sources 2a and 2b are ready for injection to the plasma. This XMP also demonstrated automatic shutoff of the neutral beams from PCS when an imminent disruption was detected.

With XMP127 finished, discharges were taken for XMP107 (Neutron Calibration Transfer). These were the first NSTX-U shots taken with full deuterium plasma fuelling—all previous discharges had helium fuelling during the plasma pulse. A number of good 1 and 2 source discharges were taken, providing initial data used to transfer the neutron calibration from count mode to current mode.

Finally, on January 8, four additional magnetics calibration shots were run under XMP106 (Magnetics Calibrations).

ITER & TOKAMAKS (R. HAWRYLUK):

F. Poli gave a USBPO web seminar on January 7 entitled "Integrated modeling in support of ITER: the path from the commissioning phase to demonstration scenarios: issues and progress." The seminar addressed three main points: (1) summarize recent modeling research in Europe and the US in support of the three demonstration discharges—baseline, hybrid and steady state—as well as highlighted results and open issues in the modeling; (2) highlight recent changes in ITER priorities where more emphasis is given to modeling and experiments in preparation of the pre-

DT campaign; and (3) stimulate a BPO working group to coordinate contributions to an ongoing ITPA-IOS activity on the modeling of helium and hydrogen discharges.

DIII-D (R. Nazikian):

R. Maingi, M. Jaworski, and R. Majeski visited DIII-D and presented a series of liquid metals seminars. Maingi's talk was "Lithium and liquid metal studies at PPPL," Jaworski presented "NSTX-U upgrade plan for liquid-metal plasma facing components," and Majeski presented "Lithium walls and enhanced tokamak performance." The talks spurred substantial discussion and interest.

The Impurity Granule Injector (IGI) vacuum system has been turned on this week after installation on the DIII-D vessel. The system pumped down to 7E-6 Torr in 24 hours. The IGI team has been given permission to run in piggyback mode on January 18 with carbon granules.

International (D. Darrow):

PPPL is preparing new thin foil Faraday cup lost alpha detectors for JET to replace units that PPPL supplied previously, some of which have failed over the decade they have been in service. This work is being done in order to prepare the diagnostic for use in the planned 2019 tritium campaign in JET. Insulator-coated nickel foils for this diagnostic were received from the vendor in December. Visual inspection shows good uniformity of the coatings, and they display excellent adhesion to the foils. Initial electrical tests show promise with regard to the insulating performance of the coatings, and further tests are underway.

ADVANCED PROJECTS (H. NEILSON):

Laboratory participation in the Wendelstein 7-X (W7-X) research program continues to move forward following the achievement of first plasma in December. N. Pablant reported the first temperature profile measurements on W7-X, using the U.S. x-ray imaging crystal spectrometer (XICS). Although both the experiment and the data are at a preliminary stage, an initial dispersion calibration of the XICS system has been completed, making the data usable within the limits of the diagnostic technique. Several U.S. contributions to W7-X operations, including the XICS data, were highlighted in the first W7-X weekly program planning meeting, held January 8.

The Laboratory is working with Germany's Max Plank Institute for Plasma Physics to develop an effective remote collaboration model for the U.S. W7-X collaboration. It is expected that remote collaboration will be an important mode of participation in the W7-X program by U.S. researchers, so a model that optimizes U.S. scientific productivity is needed. As a step toward establishing requirements, a survey of U.S. researchers is under way, soliciting input on the requirements for a remote collaboration model. The department requested survey responses to be submitted by January 22.

THEORY (A. BHATTACHARJEE):

On January 8, N. Gorelenkov presented a theory Research and Review seminar entitled "Selected topics in Energetic Particle Research in Preparations for Burning Plasmas":
"The area of energetic particle (EP) physics in fusion research has been actively studied in recent decades. The progress understanding physics in this area is substantial since the last comprehensive review on this topic by Heidbrink and Sadler (1994 Nuclear Fusion 34 535). Recently another comprehensive review was published in the same journal in preparations for burning plasmas by Gorelenkov, Pinches and Toi (2014 Nucl. Fusion 54 125001). It selects important topics of the field which will be covered in this talk. Some of them are critical for the success of ITER mission being build in France. The topics range from the 'sea' of Alfvénic eigenmodes (AEs) to high frequency cyclotron instabilities responsible for Ion Cyclotron Emission (ICE). Some other problems are also highlighted such as the plasma equilibrium in the presence of fast ions. Another important problem of interest for ST devices is the transport of the background plasma in the presence of EP driven instabilities. Many of these problems can be advanced using the expertise of PPPL theory department such as ICE which is being proposed to diagnose alphas in burning plasmas."

D. Ruiz, L. Ellison, and I. Dodin (PPPL) published a paper titled "Relativistic ponderomotive Hamiltonian of a Dirac particle in a vacuum laser field" [Phys. Rev. A 92, 062124 (2015)] where they report a point-particle ponderomotive model of a Dirac electron oscillating in a high-frequency field. Starting from the Dirac Lagrangian density, the authors derive a reduced phase-space Lagrangian that describes the relativistic time-averaged dynamics of such a particle in a geometrical-optics laser pulse propagating in vacuum. The pulse is allowed to have an arbitrarily large amplitude provided that radiation damping and pair production are negligible. The model captures the Bargmann-Michel-Telegdi (BMT) spin dynamics, the Stern-Gerlach spin-orbital coupling, the conventional ponderomotive forces, and the interaction with large-scale background fields (if any). Agreement with the BMT spin precession equation is shown numerically. The commonly known theory in which ponderomotive effects are incorporated in the particle effective mass is reproduced as a special case when the spin-orbital coupling is negligible. This model could be useful for studying laser-plasma interactions in relativistic spin-1/2 plasmas.

On January 8, Swadesh Mahajan (University of Texas, Austin) presented a theory seminar on attempting a theoretical framework for high energy density matter: "Two distinct approaches to construct a theoretical framework for fully relativistic high energy density (HED) systems- in particular, an assembly of particles in the field of an electromagnetic (EM) wave of arbitrary magnitude- are explored: 1) The Statistical-Mechanical model for the HED matter is built through the following steps: First, the eigenvalue problem for a quantum relativistic particle immersed in an arbitrary strength EM field is solved; the resulting energy eigenvalue (dependent on A, ω and k) is invoked to define the appropriate Boltzmann factor for constructing expressions for physical variables for a weakly interacting system of these field-dressed particles. The fluid equations are the conservation laws, 2) In the second approach, an equivalent nonlinear quantum mechanics is constructed to represent a hot fluid with and without internal degrees of freedom (like spin). Representative initial results are displayed and discussed. Some notable results are: 1) fundamental changes in the particle energy momentum relationship, 2) The EM wave induces anisotropy in the energy momentum tensor, 3) the EM wave splits the spin-degenerate states, 4) the propagation characteristics of the EM wave are modified by thermal and

field effects causing differential self-induced transparency, 5) Particle trapping and 'pushing' by the high amplitude EM wave. Attempts will be made to highlight testable predictions."

PLASMA SCIENCE AND TECHNOLOGY (P. EFTHIMION):

On January 6, L. Gao from Department of Astrophysical Sciences, Princeton University presented a PS&T seminar on measuring dynamics of magnetic fields in laser-driven high-energy-density plasmas for inertial confinement fusion and astrophysics: This includes precision mapping of the magnetic fields in the coronal plasma by the Biermann battery mechanism [PRL 114, 215003 (2015)] and the first measurements of magnetic field generation by the nonlinear Rayleigh-Taylor (RT) instability [Phys. Rev. Lett. 110, 185003 (2013), Phys. Rev. Lett. 109, 115001 (2012)] using ultrafast proton radiography at the OMEGA EP Laser System, University of Rochester. Planar plastic foils were irradiated with 4-kJ, 2.5-ns laser pulses at focused laser intensities of ~10^{14} W/cm^2. A high-energy proton beam tracked the hydrodynamic evolution of the target and mapped the magnetic field spatial distribution with high spatial and temporal resolution. The data show the coronal magnetic fields concentrated at the edge of the laser-focal region, well within the expanding coronal plasma, as a result of the Nernst effect. Self-similar behavior was observed in the growing cellular magnetic field structures generated by the RT instability. The calculated magnetic cell-merging rate is consistent with the value determined by earlier x-ray measurements, linking the cellular magnetic field structures with the actual RT bubble and spike growth. The experimental results are compared with resistive magnetohydrodynamic simulations, showing MG-level magnetic field generation at the surface of the laser-driven foil and inside the target. Applications in relevance to inertial confinement fusion target designs and astrophysical turbulent dynamos are discussed. Future experiments proposed on the National Ignition Facility are described.

On January 8, Yuri Podpaly from National Science Foundation presented a PS&T seminar on research focusing on the applications of x-ray and extreme ultraviolet spectroscopy with a primary focus on two areas: high temperature plasma physics and precision atomic physics. The high temperature plasma physics research took place at the MIT Alcator C-Mod tokamak, a toroidally shaped fusion reactor. Alcator C-Mod will be introduced, and the parameters and capabilities of the first imaging x-ray spectrometer deployed on a tokamak will be described. Lower hybrid current drive induced rotation and the resolution of its discrepancy among tokamaks will be presented as an example of the applications of imaging spectroscopy. Research on precision spectroscopy focusing on fusion diagnostics and basic atomic physics was performed at the National Institute of Standards of Technology (NIST) Electron Beam Ion Trap (EBIT). One area of research has been on measuring highly charged krypton in the extreme ultraviolet and x-ray regimes with systematically calculated uncertainties. Krypton n=2–n=2 and n=3–n=3 transitions were measured with six previously unidentified transitions observed and several measurements having improved uncertainties from previous results. Furthermore, a strongly electron density dependent line ratio of Al-like krypton was identified with potential applications for fusion diagnostics. Finally, some of the ongoing projects at the National Science Foundation are discussed.

DIRECTOR'S OFFICE (C. AUSTIN):

On January 7, Dr. Mike Kotschenreuther, University of Texas – Austin, presented a colloquium entitled, "Understanding the H-Mode Pedestal, Gyrokinetic Simulations and Their Implications."

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