PRINCETON PLASMA PHYSICS LABORATORY
WEEKLY highlights

PPPL
U.S. DEPARTMENT OF ENERGY

**The PPPL Highlights for the week ending March 4, 2016 are as follows:**

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

Proposed Task Agreement (TA) for Plasma Control Support: A videoconference was convened between Princeton Plasma Physics Laboratory and key members of the ITER Organization (IO) to plan for the development of a Statement of Work (SOW) for a TA that would provide support to various aspects of the development of the control and protection systems of ITER. This would include the coupling TRANSP to the ITER Plasma Control System Simulation Platform (PCSSP), the development of coil protection algorithms to be implemented in the PCSSP, the Central Interlock System (CIS) and the Plasma Control System (PCS), and the development of algorithms to provide a computationally efficient simulation of the Coil Power Supply System (CPSS) for PCSSP and PCS purposes. The plan is to develop a draft SOW and cost and schedule and pursue endorsement by IO and USDA management before the end of FY16.

Tokamak Cooling Water System (TCWS) Electrical Engineering Support: Review and consultation is provided by PPPL on electrical engineering matters related to the TCWS as part of an existing agreement between US ITER, ORNL, and PPPL. In fact, the TCWS design scope, including electrical engineering and other disciplines, has been transferred to the IO by way of an arrangement. PPPL was asked to review the status of the IO TCWS electrical engineering work and has identified some significant issues that will need to be addressed. This will most likely require a face-to-face meeting at the ITER site involving personnel from the numerous organizations involved.

**Steady State Electric Network (SSEN):**

Uninterruptible Power Supply (UPS) system and DC Distribution: Preparation of the Request for Proposals (RFPs) is underway.

Power Transformers: A punch-list of minor items was developed during the Factory Acceptance Tests (FAT) of the 10 transformers that comprise the Lot 3 shipment from the factory of Schneider Electric, near Istanbul, Turkey. Shipping will be delayed by approximately two weeks while the punch-list items are addressed. However, there is still ample float with respect to the milestone. Note that the delivery of this this shipment—by June 15—is an important ITER Council and PEMP milestone, and progress is well ahead of schedule.

**Diagnostics:**

Upper Port Wide Angle View Vis-IR Cameras (UWAVs): TNO's detailed mechanical design of the mirror cleaning test chamber was completed. The current parts list has 99 different parts, and a total of 50 drawings. All drawings are released for use. TNO's procurement plan was approved by PPPL. Quotations for most of the parts have been collected from various suppliers. Procurement of the parts with the longest lead times was initiated. The LLNL effort has been underway to quantify the diagnostic measurement performance: effect of component temperatures, measurement methods, single and dual IR color band techniques and various divertor temperatures. TNO has developed a technique to import mirror thermal deformation results from Ansys FEA into Zemax and perform optical analysis. Mirror surface deformations on the order of 1 micron can produce too much error in the imaging.

Diagnostic RGA (DRGA) R&D Magnetic Field Effects Testing: Background measurements completed which verified the linearity of the field produced by the Helmholtz coils. It was verified that mu-metal shielding is effective at reducing the external B-field in the DRGA instrumentation volume from 50G to <3G. Assuming soft iron shielding is effective to reducing the ambient B-field to <15G, then mu-metal should be able to reduce the internal B-field at the DRGA instruments to <0.5G (0.05mT). The next step is to determine magnetic field sensitivity of ion trap mass spectrometer.

EP11 Tenant Meeting: An idea was presented of connecting DRGA sampling pipe to another tenant (XRCS) rather than directly to the Closure Plate. There would be minimal benefit to RGA, but it would simplify integration of crowded closure plate and it is supported by RFDA. Conductance calculations indicate DRGA performance would not be affected. RFDA has been asked to provide a possible pipe route to determine mechanical feasibility.

Upper Port 11 and 14 Integration and DSM Engineering: A new UP#11/14 PCR has been approved which establishes a new baseline plan for the upper ports integration project. Tenant Request Forms are in process for filing in iDocs/IDM. All interfaces between Tenant and DSM have been frozen for PDR Load Spec Analysis. Investigation continues on the use of bellows in DSM water inlet/outlet pipe. A. Jariwala has sent an email to TCWS and Blanket group, requesting to share their experience on the use of bellows in piping.

Toroidal Interferometer and Polarimeter (TIP): Over the last several months, researchers from General Atomics and UCLA have been working on a prototype interferometer/polarimeter housed on a single, thermally controlled optical table at GA. A number of improvements have led to significant reductions in noise for both the interferometer and polarimeter. These have included cable and shielding changes to reduce pickup, improved thermal control, and filters to reduce sensitivity to harmonics. Recently, the fine-tuning of the co-alignment of the two lasers using a Pyrocam imager, has also led to improved stability and lower noise. A journal paper will be written which describe these results. Very soon, the laser beams will be directed off the table, along a ~ 100 meter beam path that simulates the ITER path, and back to the table. There will then be an assessment of the effects on the noise floors made by this longer beam path, and by the real-time alignment system deployed to maintain alignment along this path.

Core Imaging X-Ray Spectrometer (CIXS): Progress was made this week on setting up critical tests of the CIXS technology. The CIXS team received bids/proposals for nuclear testing of the

X-ray detector unit this week. Selection of the facility will start after Friday's deadline for submissions. Xenon crystal loan paperwork is in process to allow for crystal to be taken to MIT starting as early as next week for testing in the Alcator C-Mod. Procurement of Ti foils started for wavelength calibration testing to be performed in conjunction with Xenon crystal testing at MIT Alcator C-Mod. The team is also beginning to pursue a modified test plan for magnetic field testing on a loaned X-ray detector unit. The department is examining the use of the NSTX dummy load to apply steady state and transient fields.

**NSTX-U (M. ONO):**

A FY 2016 NSTX-U plasma operations update: The department has completed 4.81 run weeks and 482 plasma shots. The total operation targets are to be decided.

On March 1, approximately 15 additional shots were taken towards XMP-140 (PF-5 Proportional Error Field Correction Test). These shots sought to determine the optimal error field correction (EFC) proportional to the PF5 coil current at a plasma current of 900 kA. On February 25, a 900 kA ohmic reference plasma was developed first, using the optimum PF5 proportional EFC previously determined at 700 kA. Then, scans of both the correction phase and the proportional amplitude were conducted about the previous optimum correction point. The results confirmed that the optimum correction at 900 kA was very near to the optimum at 700 kA, further validating the use of these EFC tools in the development of high performance NSTX-U discharges.

On February 29, March 1, and March 2, an additional 43 shots were taken towards XMP-137 (Increase Ip and kappa in L- and H- mode). These discharges extended the parameters of an 800kA ELMy H-mode scenario including kappa (increased from 1.95 to 2.2), internal inductance (lowered from 0.9 to 0.8), stored energy (170kJ increased to 220kJ), and H-mode period (200ms increased to 600ms). The best shots from each day were 203624, 203655 and 203679. This success was enabled by up to 4MW neutral beam heating power and improvements in the error-field correction, vertical stability, and ISOFLUX shape control.

On March 3, twelve shots were taken toward XP-1506 (low-beta, low-density locked mode studies). The goal was to perform a "compass scan" by applying various phases of n=1 error fields during 700 kA ohmic discharges. The n=1 field ramp was performed on top of the optimum PF5 proportional error field correction as determined by XMP-140. Locked modes and disruptions were generated due to the applied n=1 fields, and analysis is ongoing.

On March 4, the department completed XMP-115 and isoflux control (sans X-point/Strikepoint control) by demonstrating feedback control of DRSEP and XMP-138, and vertical control by exercising the Vertical Growth Rate algorithm. These XMPs demonstrated the control algorithms for isoflux and vertical control, which functioned as expected. Several shots were also taken toward XMP-137 (Increase $I_P$ and kappa in L- and H-mode) with the goal of leveraging the new drsep control to maintain a long-pulse L-mode in USN with 1.8MW of NBI heating. The H-mode transition was avoided by using an USN shape, however the resulting plasmas were limited by MHD activity.

A successful Final Design Review (FDR) for the NSTX-U High-Z Divertor facility enhancement was held on February 29. K. Tresemer and M. Jaworski of PPPL reviewed the design, initial installation procedure, and preliminary operations guidance for the project. The FDR was deemed successful pending resolution of final CHITs allowing the project to enter procurement for machining of the continuous ring of molybdenum plasma-facing components to be installed following the FY16 run campaign this summer.

NSTX-U plasma operations continued this past week with experiments on ISOFLUX and vertical plasma control, H-mode development, low-beta error field correction, and MPTS commissioning. Plans and procedures for an argon vent of the NSTX-U vessel to retrieve boron nitride debris from a diagnostic shutter have been reviewed and will be performed during a two week maintenance period that begins this coming week. Installation activities during this maintenance period include the LoWeus/Zeus/Mona Lisa diagnostic systems, the Argon Dump system controls needed for future lithium operations, the Lithium Granule Injection system, the fast Voltage measuring system needed for CHI operations, and the new Massive Gas Injector system. The NB2B autotransformer will be replaced with a spare unit, and maintenance/repairs will be performed on the NB2C transmission lines. Weld inspections are planned for Motor Generator #1, and a test run-up of MG#2 is scheduled.

## ITER & TOKAMAKS (R. HAWRYLUK):

### DIII-D (R. Nazikian):

L. Delgado-Aparicio, E. Kolemen, and D. Gates participated in experiments on the DIII-D tokamak designed to investigate the causes of the tokamak density limit. The experiments were granted run time on DIII-D as part of the Torkil Jensen Award. The General Atomics award is bestowed on the basis of: 1) potential for transformational new results, 2) potential for producing high visibility, high impact science, and 3) collaborative effort (national or international partners). The goal of this experiment was to test ideas put forward in a recent series of papers, which have proposed that radiation driven magnetic islands are responsible for the density limit. The experiment was carried out over two run days on DIII-D and very good diagnostic data was obtained on the radiated power and plasma profiles at the onset of the density limit disruption. Preliminary analysis indicates that the 2/1 mode onset is consistent with the radiated power density matching the ohmic power density at the q=2 surface, consistent with the radiative island model. MARFEs were observed but were not a reliable predictor of disruption.

R. Hawryluk visited DIII-D and discussed the status of the collaboration with PPPL and the General Atomics staff.

### International (R. Hawryluk):

J-K. Park participated in 2016 KSTAR conference held at Daejeon Convention Center in Korea on February 24-26, and gave a plenary talk entitled "3D Field Optimization using General Perturbed Equilibrium Code (GPEC) in KSTAR." The talk reviewed the successful applications of ideal perturbed equilibrium code (IPEC) in KSTAR 3D physics problems and also the method of more general perturbed equilibrium code (GPEC) that calculates 3D equilibrium and NTV self-consistent to each other. The talk highlighted the unique capability of GPEC using the coil-to-torque response function, which provides all the information required to optimize NTV with a given set of coils. A couple of interesting applications and examples were shown, such as the maximum/minimum torque that the KSTAR n=1 can produce, or the n=1 current amplitude and toroidal phase for each row to maximize or minimize local torque at a given radius. Park also participated in 2016 KSTAR research forum and presented two experimental proposals: (1) "Search of most quiescent magnetic braking"—MP2016-02-12-060; and (2) "Continuous and coherent n=1 phase-shift (phasing) sweeping using all 3 rows (revisited)"— MP2016-02-15-003. The purpose of (1) is first to clarify a recent issue on most non-resonant n=1 field between -90 phasing and 0 phasing, and further to optimize n=1 and n=2 3D field configurations to produce only rotation braking while minimizing other transport effects such as density pumping. Experiment (2) is to scan all the possible n=1 phasing by rotating n=1 field at the top and bottom in opposite directions while fixing n=1 field at the midplane, and see if a magic setting exists for ELM suppression on a given target discharge. Last year, this experiment suffered from low coil currents, limited by 2.5kA, and thus was proposed again this year by anticipating one more power supply available that would increase the maximum currents up to 5kA.

D. Mueller attended the KSTAR Conference and presented a poster on vertical control improvements for KSTAR. He also attended the second half of the KSTAR Research Forum and made a proposal for experiments to commission and implement changes to the fast vertical control on KSTAR. Subsequently, he met with J.G. Bak and S.H. Hahn to make plans for improving the fast vertical position diagnostics required for that proposal. H. Park agreed to provide the support for those changes.

**ADVANCED PROJECTS (H. NEILSON):**

N. Pablant returned to Greifswald, Germany to participate in the last two weeks of the first Wendelstein 7-X experimental campaign at the Max Planck Institute for Plasma Physics. An experimental proposal entitled: "016: Investigation of Argon Impurity Transport in W7-X Limiter Configuration," which occurred over multiple experimental run days, was completed last week. This experiment consisted of investigating impurity transport in a wide range of plasma conditions including helium and hydrogen plasmas, density scans, power scans, and off-axis heating location scans. The U.S. X-ray imaging crystal spectrometer (XICS) diagnostic was a centerpiece of this experiment as it allows time resolved measurements of the argon 16+ density profiles. Core impurity transport is a critical topic for reactor design, particularly with respect to the topics of heavy impurity radiation and accumulation of helium ash.

**THEORY (A. BHATTACHARJEE):**

On February 29, S. Janhunen (PPPL) presented a theory seminar on mixed finite-element/finite difference method for toroidal field-aligned elliptic electromagnetic equations. The abstract reads: "Gyrokinetic simulations—such as those performed by the XGC code—provide a self-consistent framework to investigate a wide range of physics in strongly magnetized high temperature laboratory plasmas, global modes usually considered to be in the realm of MHD simulations. However, the present simulation models generally concentrate on short wavelength electro-magnetic modes mostly to convenience the field solver performance. To incorporate more global fluid-like modes, also non-zonal long wavelength physics needs to be retained. In this work we present development of a fully 3D mixed FEM/FDM electro-magnetic field solver for use in the gyrokinetic code XGC1. We present optimization for use on massively parallel computational platforms, investigation of numerical accuracy characteristics using the method of manufactured solutions, and evaluate importance of field line length calculations on the stability of the discretization. We also invite discussion on the importance of the perpendicular vector potential for pressure driven modes."

On March 3, Holger Heumann (INRIA, France) presented a theory seminar on free-boundary axisymmetric plasma equilibria. "Computational methods and applications: We present a comprehensive survey of the various computational methods for finding axisymmetric plasma equilibria. Our focus is on free-boundary plasma equilibria, where either poloidal field coil currents or the temporal evolution of voltages in poloidal field circuit systems are given data. Centered around a piecewise linear finite element representation of the poloidal flux map, our approach allows in large parts the use of established numerical schemes. The coupling of a finite element method and a boundary element method gives consistent numerical solutions for equilibrium problems in unbounded domains. We formulate a Newton-type method for the discretized non-linear problem to tackle the various non-linearities, including the free plasma boundary. The Newton method guarantees fast convergence and is the main building block for the inverse equilibrium problems that we discuss as well. The inverse problems aim at finding either poloidal field coil currents that ensure a desired shape and position of the plasma or at finding the evolution of the voltages in the poloidal field circuit systems that ensure a prescribed evolution of the plasma shape and position. We provide equilibrium simulations for the tokamaks ITER and WEST to illustrate performance and application areas."

**PLASMA SCIENCE & TECHNOLOGY (P. EFTHIMION):**

On March 2, Professor Richard Wirz from UCLA presented a seminar on "Canonical Characterization of Plasmas for Electric Propulsion." The abstract reads: "UCLA's Plasma and Space Propulsion Laboratory investigates topics ranging from plasma physics for propulsion and metamaterials, applied plasma science, and electric propulsion technology. This talk will first discuss some of the micro electric propulsion technologies developed in our lab, including the world's first miniature noble gas ion thruster (MiXI: Miniature Xenon Ion) and the world's first miniature Hall thruster that uses magnetic shielding (MaSMi: Magnetically Shielded Miniature). Missions for these thrusters include formation flying and micro- and nano-satellite exploration missions to the Moon and nearby asteroids. The bulk of this talk will discuss canonical experiments and modeling for low-temperature plasma conditions, as found in most electric propulsion devices. A recent experiment/modeling/theory effort in our lab, which was featured on the cover of Physics of Plasmas, revealed that plasma cusp confinement at the micro-scale does not follow conventional theory for hybrid loss width (i.e., traditionally assumed to be the geometric mean for ion and electron gyro radii, rhybrid$\propto$rire). In contrast, our analyses show dramatically different loss behavior at the micro-scale, which can be explained by careful consideration of the upstream magnetic field and the related electron drift to explain electron and plasma loss. Another effort has provided the first ever, canonical data for ion-neutral interactions, with computational PIC/MC characterization and analysis. The talk will conclude with a brief discussion of our recent efforts to investigate plasma conditions very near a material surface, and the implications of the surface material and structure on plasma-material interactions. In particular, we have developed the UCLA Plasma-Material Interactions (UCLA-

Pi) experiment that uses an axially magnetized cylindrical plasma discharge to deliver a wide range of plasma conditions to a material target. By correlating plasma density and potential oscillations, we have found that a coherent, low-frequency m = 1 oscillation may be the main source of cross-field electron transport for certain operating conditions in this device. We have also found that these types of plasma conditions can also have strong influence on plasma-material interaction behavior at the target."

## BEST PRACTICES & OUTREACH (J. DELOOPER):

### Science Education (A. Zwicker):

On February 27, Coleen Murphy (Princeton University) presented the Science on Saturday lecture, "Brutal Efficiency: How Mating and Reproduction Influence C. Elegans Longevity."

On March 5, Ed Synakowski (U.S. Department of Energy) presented the Science on Saturday lecture, "Re-imagining the Possible: Scientific Transformations Shaping the Path Towards Fusion Energy."

## DIRECTOR'S OFFICE (C. AUSTIN):

On March 2, Professor Charles Hall from the State University of NY College of Environmental Science and Forestry, presented a colloquium entitled, "History, Applications, Numerical Values, and Problems with the Calculation of EROI - Energy Return on (Energy) Investment."

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