Weekly HIGHLIGHTS

PPPL PRINCETON PLASMA PHYSICS LABORATORY
U.S. DEPARTMENT OF ENERGY

The PPPL Highlights for the week ending November 3, 2018, are as follows:

NSTX-U RECOVERY AND RESEARCH (J. MENARD)

Recovery:

Vacuum Vessel & Internal Hardware (VV+IH) — The center stack heating/cooling transfer tubes (HTT) and transfer plates (HTP) underwent a final design review (FDR) on Nov. 1. The FDR covered HTT design, manufacturing, and installation for center stack inboard divertor vertical PFC tile cooling during operation, and HTP design, manufacturing, and installation for center stack inboard divertor horizontal PFC tile cooling during operation and tile heating during bakeout. The FDR was held to review HTT and HTP design developments that have evolved since the preliminary design review stage, and to confirm the final design before procurement, manufacturing, and re-work. The FDR was successful, pending resolution of chits.

Management — K. Roberts of SM&A in Irvine, California, conducted training on the earned-value management system (EVMS) for recovery project control account managers (CAMs) and associate project managers (APMs) on Oct. 30 and 31. EVMS is a project management technique for measuring project performance and progress in an objective manner. The NSTX-U Recovery Project is required to implement EVM, and the training was to enhance knowledge for project team members who will use it.

Magnets — The updated Magnet WAF (Work Approval Form) with the basis of estimate (BOE) was completed this week and is under review, and a first draft of the source selection plan is underway. A meeting was held with ETI in which they presented their ideas for mitigating vacuum pressure impregnation (VPI) issues should they be chosen to produce the inner PFC coil. Two magnet team members are on site at ICAS Tratos for the conductor grit blasting and priming. Inspections were made of the additional cut-through of a section of Tesla coil; the quality of the VPI looked comparable to the first section, which resulted in no changes to original rankings and conclusions. Modifications were made last week to the water fitting assembly prototype to accommodate the pressure test fitting connection.

Research:

Collaboration Activities — F. Poli attended the ITPA-IOS meeting from Oct. 29-31 at the ITER headquarters. In an effort to improve communication between topical groups, this meeting has initiated short reports from the meetings of other topical groups. Poli is the contact between the Energetic Particle ITPA group and the Integrated Operation Scenarios group. She reported on possible topics for joint activities between the groups

and on common needs, the most important identified as the need for developing reduced models for anomalous transport for integration into time-dependent simulations scenarios for ITER.

Program Activities — T. Looby (University of Tennessee at Knoxville) successfully defended his master's thesis titled, "Heat Flux Model Validation Utilizing Convolutional Neural Networks and Sub-surface Thermocouples for NSTX-U," on Oct. 29. This work was motivated by the desire for a conservative means of power accounting and model-based control of heat flux for future NSTX-U scenarios, and used the new recovery-era PFC design featuring castellated blocks of graphite and embedded thermocouples (TCs). This work demonstrated that the parametric scaling of the SOL heat flux width, lambda-q, could be extracted from the thermocouple data using a neural network trained on ANSYS simulations, even in the presence of systematic error in the TCs. Thomas' work will be presented as a poster in the NSTX-U session at the 2018 APS-DPP meeting in November and was supervised by M. Reinke (ORNL) and D. Donovan (UT-K).

M. Podestà (NSTX-U/PPPL) has been elected vice-chair of the US Transport Task Force (TTF) Executive Committee, which is in charge for organizing the annual TTF meeting. The next TTF meeting will be held in Austin, Texas.

U.S. ITER FABRICATION (H. NEILSON)

The Low Field Side Reflectometer (LFSR) project team completed preparations for its preliminary design review, which will take place Nov. 7-8 at the ITER project site in St. Paul-lez-Durance, France. Dry runs of 24 presentations to be given by PPPL and General Atomics team members were conducted. Revisions to several key deliverable documents, responding to comments from central team staff, were completed and submitted. A briefing on the status of the LFSR project was presented by H. Neilson to DOE Fusion Energy Sciences and Princeton Site Office management teams.

ITER & TOKAMAKS (R. NAZIKIAN)

International PMI (R. Maingi):

An article titled, "ELM frequency enhancement and discharge modification through lithium granule injection into EAST H-modes" by R. Lunsford et. al., has been published in *Nuclear Fusion*: https://doi.org/10.1088/1741-4326/aae2c1). The article describes lithium granule injection into EAST and notes for the first time the ability of high-frequency granules, at sizes below the prompt ELM-triggering threshold, to affect an overall increase in the global ELM frequency and a subsequent reduction in the peak ELM intensity. Specifically, 200-micron granules injected at frequencies up to 2.3 kHz

were able to increase the ELM frequency from 250 Hz to 620 Hz resulting in a 50% decrease in peak ELM size as measured by D-alpha intensity.

DIII-D Research (B. Grierson)

A new paper, “Direct Observation of Nonlinear Coupling between Pedestal Modes Leading to the Onset of Edge Localized Modes,” by A. Diallo, J. Dominski, K. Barada, M. Knolker, G.J. Kramer, and G. McKee, has been accepted for publication in *Physical Review Letters*. This paper uses DIII-D data in type-I ELMy H-mode to show for the first time that coupling of modes leads up to the ELM onset. Three dominant pedestal modes, exhibiting both magnetic and density fluctuations, have been identified, and their amplitudes, frequencies, and radial profiles have been tracked during the ELM cycle. The nonlinear coupling of these pedestal modes is associated with radial distortions pushing out of the pedestal prior to the ELM event.

A new paper titled, “Fast and pervasive heat transport induced by multiple locked modes in DIII-D,” by Q. Hu, X. Du, Q. Yu, N.C. Logan, E. Kolemen and R. Nazikian has been accepted for publication in *Nuclear Fusion*. The nonlinear MHD code (TM1) was used to simulate the effect of multiple locked modes on heat transport and found that the co-existence of 2/1, 3/1 and 4/1 locked islands can produce a large (>50%) reduction in electron temperature. The simulation well reproduced DIII-D experimental results and provided a better understanding for the transition from locked modes to major disruption.

R. Nazikian attended the ITPA Pedestal and Edge Physics fall meeting with A. Ashourvan (remote). A pair of talks was presented showing the grassy-ELM-controlled steady-state scenario conditions relevant to Q=5 ITER operation demonstrated on DIII-D, with regular transitions between grassy ELMs and an ELM-suppressed pedestal. During ELM suppression the pedestal is within 10% of the kinetic ballooning mode (KBM) limit, but during grassy ELMs, the pedestal has local flattening in the steep gradient region where low levels of ExB shear exist. Calculations with the CGYRO code indicate that low-wavenumber, linearly unstable turbulent modes are more likely to exist in this region with reduced turbulence suppression, and a feedback mechanism for the oscillation between the two states was proposed.

B. Grierson has been elected to the edge coordinating committee (ECC) and will contribute to coordinating pedestal and core-edge integration research on DIII-D.

A. Bortolon visited MIT's Plasma Science Fusion Center to present a seminar titled, “Real-time wall conditioning through low-Z dust injection in tokamak plasmas.” The seminar reviewed the basic principles of wall conditioning principles and most

established techniques and introduced the results of recent experiments on real-time wall conditioning with boron dust injection in ASDEX-Upgrade and DIII-D.

DIII-D Operations and Control (A. Nagy, K. Erickson):

Both of two calorimeters fabricated by PPPL for the 210 Co/Counter Off-Axis Neutral Beam project have been installed in the neutral beam spools. Water lines and thermocouples will be connected to the system next. The neutral beam is being assembled in the DIII-D high bay area before installation in the machine pit.

A new paper entitled "A Multi-Species Powder Dropper For Magnetic Fusion Applications," by A. Nagy, A. Bortolon, D. M. Mauzey, E. Wolfe, E. P. Gilson, R. Lunsford, R. Maingi, D. K. Mansfield, R. Nazikian, and A. L. Roquemore has been published in *Review of Scientific Instruments:* https://doi.org/10.1063/1.5039345. This paper details a new device for controlled injection of a impurities (B, BN, C) in powder form. The system implements four independent feeder units, arranged to share a single vertical drop tube. Each unit advances a layer of powder by piezoelectric agitation at a speed proportional to the applied voltage until it is delivered into a drop tube. A calibrated LED-based flow meter measures and monitors the drop rate during operation. The fast time-response of the four feeders allows combination of steady and pulsed injections that provide a flexible tool for controlled-dose, real-time impurity injection in fusion plasmas.

The final design review (FDR) for the DIII-D's Lyman-alpha diagnostic was successfully held at General Atomics. The diagnostic, developed under a PPPL-MIT collaboration led by J. Hughes (MIT) and A. Bortolon (PPPL), enables the determination of the main ion ionization source, a key unknown in all studies of pedestal transport and structure in present-day tokamaks. The FDR was presented by MIT graduate student A. Rosenthal, who discussed the technical solutions to the outstanding challenges posed by the use of in-vacuum optical components and detectors, in particular with regard to compatibility with the high temperature baking and boronization. The project moves now into the purchasing and fabrication phase. The Lyman-alpha diagnostic is expected to be installed on DIII-D, and will be operational during the upcoming FY19 experimental campaign.

International 3D and stability (J-K. Park):

Z.R. Wang submitted the paper titled, "Identification of multiple eigenmode growth rates in DIII-D and EAST tokamak plasmas," to *Nuclear Fusion* as a letter. The paper describes an advanced MHD spectroscopy extracting multi-mode responses and eigenmodes directly from 3D field experiments, based on multi-modal transfer functions

for magnetic measurements. The growth rates (damping rates) and variation of dominant eigenmodes in n=1 multi-modal plasma response are identified in DIII-D and EAST experiments. This new method can be used to optimize time-varying 3D plasma response and to predict MHD instabilities in tokamaks.

KSTAR MSE (S. Scott):

Continuing analysis of the secondary beam emission process in KSTAR, which is a process that confuses the beam-into-gas calibration of the MSE diagnostics, has identified a peculiar and potentially useful behavior. For most values of the magnetic field pitch angle, the secondary emission generates polarized light at polarization angles that differ from the polarization angle of the primary (i.e., desired) emission. This secondary emission combines with the primary emission and thereby changes the net polarization angle. But both numerical and analytic analysis indicates that for a pitch angle of zero — i.e., a horizontal magnetic field line — the polarization angle of the secondary emission should be identically equal to that of the primary emission. Thus for a pitch angle of zero, we expect that the secondary emission would not change the net polarization angle. Experimentally, we observe that the effect of secondary emission is not quite zero for pitch angle=0, but it is reduced a factor of ~20 compared to other pitch angles. This behavior may be useful in using beam-into-gas calibrations to determine e.g. the Faraday rotation in the MSE optics even in the presence of secondary beam emission.

ADVANCED PROJECTS (D. GATES)

Stellarators (D. Gates):

At the IAEA meeting in Gandihar, India, N. Pablant presented a paper entitled, "Investigations of the role of neoclassical transport in ion-root plasmas on W7-X." This paper presents the first experimental evidence that ion-root conditions (negative radial electric field over the entire plasma core) have been achieved in W7-X. This is an important result, since it shows that the conditions for which W7-X has been optimized are accessible, namely high-density ECRH heated plasmas with Te ≈ Ti and a negative Er. Measurements of the radial electric field profile were made using the PPPL-supplied XICS diagnostic that has been installed on W7-X. Calculations of the neoclassical ambipolar electric field for these plasma conditions have been completed though the use of the code SFINCS (M. Landreman, University of Maryland), and compared with the measured results. These comparisons show good agreement across the entire plasma core where measurements are available, and provide confidence in the accuracy of neoclassical calculations in the optimized W7-X ion-root conditions. Building from this validation of the neoclassical Er profile, calculations of the neoclassical electron and ion

flux profiles have been calculated and compared to the plasma heating. It is found that when the plasma is in the ion-root phase neoclassical heat transport can account for more that 60% of the core transport. This can be contrasted with calculations in moderate density electron-root plasma at similar power where neoclassical transport can only attribute for less that 30% of the core transport.

THEORY (S. HUDSON)

Many members of the theory department attended the 27th IAEA Fusion Energy Conference in India, Oct. 22-27. S.-H. Ku gave a talk titled, "A gyrokinetic discovery of fast L-H bifurcation physics in a realistic diverted tokamak edge geometry." The following posters were presented: J. Chowdhury, "Gyrokinetic Neoclassical Study of the Effect of the X-Point Height on Eˆ B Flow Structure in an H-Mode Edge Plasma;" M. Churchill, "Pressure Balance in a Low Collisionality Tokamak Scrape-Off Layer;" M. Cole, "Confinement in Stellarators with the Global Gyrokinetic Code XGC;" R. Hager, "Gyrokinetic-MHD Coupled Simulation of RMP Plasma Interaction Reproduces Density Pump-Out Seen in the Tokamak Edge;" A. Hakim, "Continuum Gyrokinetic Simulations of NSTX SOL Turbulence with Sheath-Limited Model Geometries;" C. Liu, "Energy Loss and Radial Diffusion of Runaway Electrons due to Kinetic Instabilities;" A. Reiman, "Equilibrium Pressure-Driven Current in the Presence of a Small Magnetic Island: Singular Behaviour and Symmetry Effects;" and W. Wang, "Self-Driven Current Generation in Turbulent Fusion Plasmas."

C.S. Chang presented two posters: "Total-f Gyrokinetic Turbulent-Neoclassical Simulation of Global Impurity Transport and its Effect on the Main-Plasma Confinement," and "Wide Divertor Heat-Flux Width in ITER from Self-Organization between the Neoclassical and Turbulent Transports across the Separatrix Surface." N. Ferraro also presented two posters: N.M. Ferraro, et al, "Error Field Impact on Mode Locking and Divertor Heat Flux in NSTX-U," and I. Krebs, et al, "Nonlinear 3D Simulations of Vertical Displacement Events in Tokamaks."

Computational Plasma Physics Group (S. Jardin):

E. Feibush and S. Ethier gave lectures at the Princeton University Research Computing Bootcamp 2018, which was organized by the Princeton Institute for Computational Science and Engineering (PICSciE) and co-sponsored by the School of Engineering and Applied Science, the Princeton Neuroscience Institute, The Program in Applied and Computational Mathematics, and The Center for Statistics and Machine Learning. This four-day boot camp provided graduate students and postdocs an introduction to a variety of topics, tools, and techniques used in modern computational research.

(https://princetonuniversity.github.io/PUbootcamp/). Feibush gave a lecture on scientific visualization while Ethier gave an introduction to code debugging.

ENGINEERING (V. RICCARDO)

Last week, P. Titus attended a conceptual design review of COMPASS Upgrade, which is a small (Ro=.894m) high-field (5T) copper machine. COMPASS Upgrade is planning to accommodate a vessel that can operate at 350 to 500C. This will allow COMPASS Upgrade to explore more divertor options, more plasma material interactions and will support liquid-metal divertors and first-wall experiments. The design is extensively supported with analysis and mechanical design but key areas need further assessment. The copper TF coil joints have not been analyzed for electromagnetic transients and the local joint current densities have been underestimated. The global structural simulation relies on a bucked and wedged solution and the fit-up issues have not been considered. The OH coil is overstressed and lacks intermodule alignment features. The Czech IPP engineers were enthusiastic about collaborations with PPPL and are hoping to visit the Lab in December. The review committee was chaired by T. Todd and included representatives from JET, ITER an ASDEX as well as PPPL.

SITE PROTECTION (M. COHEN)

Members of Site Protection and Emergency Services participated in the Department of Homeland Security (DHS) Bombing Prevention Awareness program. ESU members completed their physical agility testing, and ESU conducted training on high-rise fires. Engine 66 responded to two mutual aid assignments in Princeton and Plainsboro Townships. Ambulance 166 responded to one mutual aid assignment in Plainsboro Township.

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