Weekly HIGHLIGHTS

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

The PPPL Highlights for the week ending June 6, 2020, are as follows:

NSTX-U RECOVERY (J. GALAYDA) AND RESEARCH (S. KAYE)

Recovery (J. Galayda):

Management — The Project office has begun preparations for resumption of onsite work. This includes assessing the need for specialized personal protective equipment (PPE) for work in confined spaces. The team is preparing detailed procedures and work schedules for installation.

Coils — Coil winding continued in France at Sigmaphi. PF1BL passed electrical testing and was packaged for shipment to PPPL, and PF1AL was cured from the vacuum pressure impregnation (VPI). Winding of the PF1AU coil continued with winding of the 4th (last) layer this week. PF1CL winding was completed this week, and the coil was prepped for VPI. Winding of the PF1CU coil also began this week. PPPL oversight (both Engineering and Quality Assurance) witnessed all activities and were in daily contact with the PPPL cognizant engineer. Shipping packaging of the PF1B coil was carefully reviewed by all parties, and shipment is expected next week.

Center Stack Casing (CSC) — Machining of the center stack casing continued in Camden, New Jersey, at the Holtec Machining Division facility. PPPL was engaged in procuring oversight engineers for both the Camden and Turtle Creek sites to provide on-site oversight of ongoing activities.

Machine Core Structure (MCS) — Fabrication efforts of many MCS parts were pursued at three different facilities since the COVID-19 curtailment of PPPL fabrication activities. Precision Boring in Michigan will ship preload parts next week to a coating vendor. In addition, PF1B sling parts have all passed first article inspections and are in production. PF1C capping flanges are also in fabrication. The MIT plans for the PF1A and PF1B capture flanges and the PF1A/B common flanges are in comment resolution. PF1A sling part work at Carolina Fabricators is working through first article inspections. G. J. Oliver continued fabrication of the PF1C coil supports, and the lower coil support was welded and machining began this week.

Heating Systems Modulator/Regulator System Peer Review — A peer review was held June 3 to cover the scope for the neutral beam control system modifications on the modulator/regulator electronics components and interfaces. This includes collection of maintenance and incremental improvements intended to improve the reliability, availability, and maintainability of the NBIS modulators. The main purpose of this work

is to manage down obsolescence of parts that are no longer available, and to get rid of obsolete circuitry that is no longer used but is embedded in old electronics.

U.S. ITER FABRICATION (H. NEILSON)

The Toroidal Interferometer Polarimeter (TIP) diagnostic is being designed to measure the density along five toroidal chords in the ITER plasma. With work resuming on this system following a three-year hiatus, several urgent items are being addressed under the leadership of PPPL engineer M.-A. de Looz. Captive components (items which, once installed, cannot be accessed at a later date) such as the gallery-to-diagnostics hall penetrations will be installed in the near term at ITER. This requires the team to conduct a beamline identification to aid in the construction process documentation for this early step. Separately, the diagnostics hall for TIP will contain extensive and complex temperature-regulated laser systems and must comply with recent developments in laser safety at ITER. A positive review of layout changes was conducted with experts, ensuring the new design can still fundamentally meet baseline equipment and diagnostic performance requirements.

The Upper Wide Angle Viewing (UWAVS) design team met with Central Team counterparts to discuss interfaces with neighboring diagnostics, including the H-alpha diagnostic. Design developments during the three-year hiatus in UWAV have impacted the configuration, requiring the designs and interfaces to be re-visited. During the meeting these details and model for the H-alpha beam path was clarified, enabling work on that system by the Russian team to move forward.

The Low Field Side Reflectometer (LFSR) design team has continued to finalize and submit documentation for the final design review (FDR) of its in-vessel antenna assembly. A reliability, availability, maintainability, and inspectability (RAMI) document which updates the RAMI assessment of the in-vessel equipment was approved by U.S. ITER and submitted to the ITER organization. Four engineering analysis reports, documenting the system integrity against electromagnetic, nuclear heating, bakeout, and various structural loads, are in final review. The Design Compliance Matrix (DCM), which documents compliance of the design with system requirements, is undergoing final reviews.

ITER & TOKAMAKS (R. NAZIKIAN)

The Princeton University/PPPL Deep Learning Code FRNN has been successfully deployed in the DIII-D Plasma Control System (PCS) during the start-up phase, involving more than 150 shots from May 7 to the present. The real-time capability has been demonstrated by passive execution of the code during startup shots without feedback

into the PCS. The FRNN computing time was found to be demonstrably fast and stable with a short 1.7-millisecond mean runtime and a standard deviation of less than 20 microseconds. The achievement from the present FRNN execution is that it is the first deep learning predictor successfully integrated into the DIII-D PCS that can be readily functional during real-time operations. As such, plans are now being actively developed for systematic actuator testing with the goal of demonstrating the ability to modify the plasma state to avoid or delay the onset of disruptions.

DIII-D (B. Grierson):

Research:

Nuclear Fusion published the paper titled, "Real-time pedestal optimization and ELM control with 3D fields and gas flows on DIII-D," by F. Laggner, D. Eldon, A. Nelson, C. Paz-Soldan, A. Bortolon, T. Evans, M. Fenstermacher, B. Grierson, Q. Hu, D. Humphreys, A. Hyatt, R. Nazikian, O. Meneghini, P. Snyder, E. Unterberg, E. Kolemen, and the DIII-D team: https://doi.org/10.1088/1741-4326/ab88e1. Three new control schemes allowing pedestal optimization and ELM control by magnetic perturbations were implemented into the DIII-D plasma control system (PCS) and successfully deployed in experiments. Pedestal control allows the exploration of core-edge integrated plasma scenarios in present-day tokamaks. With respect to ITER, the need for an advanced control system is highlighted to keep the applied 3D fields close to the ELM suppression threshold at all times, enabling high fusion energy gain.

Nuclear Fusion also published the paper entitled, "Nonlinear modeling of the scaling law for the m/n = 3/2 error field penetration threshold:" https://doi.org/10.1088/1741-4326/ab8b79. The authors were Q. Hu, N. Logan, J.-K. Park, C. Paz-Soldan (GA), R. Nazikian, and Q. Yu (IPP). The scaling of error field penetration threshold is modeled by using the nonlinear MHD code TM1 for both single-fluid and two-fluid simulations. The scaling from single-fluid simulations is similar to the analytical error field scaling, while the scaling law from two-fluid simulations shows significant difference depending on plasma parameters. This work highlights the importance of both electron temperature and two-fluid effects in EF scaling.

The article, "Experimental evidence of ECCD-based NTM suppression threshold reduction during mode locking on DIII-D" by A. Nelson, N. Logan, W. Choi, E. Strait, and E. Kolemen was accepted as a Special Issue Article for publication in *Plasma Physics and Controlled Fusion*. In collaboration with colleagues at DIII-D, the PPPL team investigated a unique set of discharges with repetitive locking-unlocking of a large m/n = 2/1 neoclassical tearing mode (NTM.) They found that partial suppression of a locked NTM is

aided by the reduced bootstrap current and beta present after a back transition to L-mode, possibly widening the window of potential disruption avoidance in ITER.

The article, "Full-orbit simulations of fast-ion charge-exchange losses induced by neutral particles outside the plasma last closed flux surface," by G. Kramer, M. van Zeeland, and A. Bortolon was accepted for publication by *Nuclear Fusion*: https://doi.org/10.1088/1741-4326/ab992d. The researchers studied the interaction between neutrals outside tokamak plasmas and fast ions that are generated by neutral beam injection and pass outside the plasma. The team shows that at beam energies up to approximately 100 kiloelectron volts, fast-ion losses are significant, up to 20% in the studied case, because of charge exchange reactions between the neutrals and the fast ions. About half of the fast ions that neutralize outside the plasma get lost to the wall while the other half re-enters the plasma and ionizes again, often on better confined orbits which is visible as an enhanced beam power deposition in the plasma core. As a result, the plasma performance as measured from the beam-thermal neutrons is hardly changed despite the significant fast-ion losses toward the plasma edge.

Operations:

International PMI and FES LM PFC Development Program (R. Maingi):

Fusion Engineering and Design published a paper titled, "Development of a new TZM substrate flowing liquid lithium limiter for high performance plasma discharge in EAST," by C. Li, G. Zuo, R. Maingi, X. Meng, W. Xu, Z. Sun, et al. The paper describes heat exhaust calculations for the helium gas cooling loop that was part of the molybdenum substrate third-generation flowing liquid lithium limiter that was constructed by PPPL and implemented in EAST. The paper also presented the first results from insertion into high-power H-mode plasmas showing ELM mitigation and slightly improved energy confinement.

Two periodic meetings of the domestic liquid-metal plasma-facing component design activity were conducted. In the first meeting, S. Smolentsev (UCLA) summarized previous calculations and proposed calculational and experimental directions for the LM PFC design activity. In the second meeting, technical talks were given by C. Kessel ("Evaporation and temperature limits for liquid lithium PFCs") and D. Andruczyk ("Highlights of recent UI-UC experimental and analysis activities").

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ADVANCED PROJECTS (D. GATES)

Stellarators (D. Gates)

A paper written by A. Langenberg (IPP) with N. Pablant (PPPL) as one of the primary co-authors has been selected to be highlighted by *Physics of Plasmas*. The paper is titled, "Charge-state independent anomalous transport for a wide range of different impurity species observed at Wendelstein 7-X:" https://doi.org/10.1063/5.0004462. This research was made possible by the two X-ray imaging crystal spectrometers (XICS and HR-XIS) that were installed on W7-X as a collaboration between PPPL and IPP. Pablant played a leading role in the development of the experimental plan that enabled this research and served as session leader for these experiments in 2018. The highlight, "Stellarator impurity transport experiments show a favorable anomalous transport mechanism," can be found here: https://doi.org/10.1063/10.0001355.

A thesis titled, "Interpretation of synergistic effects between electron beam and microwave startup of a torsatron plasma" was submitted to Technische Universität Wien (Technical University of Vienna) by master's student M. Werl. The thesis described the development of a code intended to assess potential physical mechanisms behind some plasma heating experiments in the CNT stellarator at Columbia University. K. Hammond served as an informal advisor on the project.

Thanks to the support from A. Mollen and N. Pablant, F. Nespoli was able to successfully run the SFINCS code on the Eddy cluster at Princeton University. First calculations of the ambipolar radial electric field have been performed to interpret LHD experiments employing the PPPL designed-and-built impurity powder dropper.

THEORY (S. HUDSON)

Nuclear Fusion has accepted the paper, "Simulation of MHD instabilities with fluid runaway electron model in M3D-C1" by C. Zhao, C. Liu, S. Jardin, and N. Ferraro for publication.

A paper by A. Glasser and H. Qin titled, "The geometric theory of charge conservation in particle-in-cell simulations" was published by *Journal of Plasma Physics*: https://doi.org/10.1017/S0022377820000434. Using the tools of discrete differential geometry, the paper systematically develops a theory for designing structure-preserving geometric particle-in-cell (PIC) algorithms with gauge symmetry and the charge conservation law. As an application, a novel, explicit, canonical symplectic, gauge-compatible splitting PIC method was designed.

Physics of Plasmas published,"Charge-state independent anomalous transport for a wide range of different impurity species observed at Wendelstein 7-X," by A. Mollen: https://doi.org/10.1063/5.0004462. Also, a Scilight, "Stellarator impurity transport experiments show a favorable anomalous transport mechanism" was published here: https://doi.org/10.1063/10.0001355

COMMUNICATIONS & PUBLIC OUTREACH (A. ZWICKER)

Communications (L. Bernard):

The Office of Communications posted one news story to the PPPL website. It reported on research by D. Schaeffer and others into the shock waves created by plasma pistons. Results could deepen our understanding of space weather. The story was also posted to the *Newswise* and *EurekAlert* press release distribution services.

DIRECTOR'S OFFICE (S. COWLEY)

Laboratory leadership has been communicating ongoing updates to staff regarding the COVID-19 virus and PPPL.

A virtual colloquium was presented on June 3 by S. Prager of Princeton University and PPPL titled, "The Increasing Peril from Nuclear Arms: And How Physicists Can Help Reduce the Threat."

This report is also available on the following web site:

http://www.pppl.gov/publication-type/weekly-highlights