Weekly HIGHLIGHTS

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

The PPPL Highlights for the week ending January 30, 2021, are as follows:

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

Recovery (J. Galayda):

Bus Supports —The water-cooled power cable repairs continued at the vendor with an improved closure design. The materials required for the PF extension and OH coax bus connection were inspected and prepared for fabrication of the supports in conjunction with the work packages.

Coils — The prototype B coil was installed on the Haas for validation of the machining plan for production coils. The machining of the prototype results will be presented in a peer review next week. Other repairs for machining the production coils continued at PPPL.

Center Stack Casing (CSC) — The finish machining in Camden, New Jersey, of the OD of the CSC was on hold due to a machining error at the Camden facility. An investigation into the root cause was performed by the Holtec quality assurance organization. At Turtle Creek, the bellows mockup welding distortion issue with the diverter flange was still being worked on between Holtec and PPPL Engineering. Preparations continued for a second mockup.

Machine Core Structure (MCS) — Precision Boring in Michigan continued with fabrications. The capture flanges were completed and the common flanges were in final inspection. PPPL requested enlargement of several flange holes to improve clearances, which will be accomplished in the next week; all four flanges will then be shipped to PPPL. Fixture plates fabrication was also in inspection and spare PF1B coil components were being fabricated. In South Carolina, Carolina Fabricators production of PF1A sling base parts was completed and shipment is ongoing. G. J. Oliver continued with machining of the outer skirt support, and the ceramic break flange arrived at PPPL.

At PPPL, assembly procedures were in review for PF1A and PF1b coil assemblies. PF1B lower slings welding was completed, base plate drilling continued, and ongoing and post-weld inspection and heat treating began. Upper PF-1B sling welding began, along with preparations to weld the PF1A slings. The PF1CL support was dimensionally checked and will move into welding, cleaning, and testing. PF1CU was dimensionally checked.

TF Bundle and Casing Assembly Alignment and Case Lift Fixture FDR — A final design review (FDR) was held Jan. 26 to review the design of the lift fixture and the assembly process for the center stack casing and case support stand to identify the potential component mating issues, interferences for lifting fixtures, and TF bundle and casing assembly alignment / positioning fixture. This FDR also completed a previous peer review of the CS casing lift fixture and case stand design.

PF4-5 Coil BUS Reconnection Peer Review — A peer review was held Jan. 28 to review the design of additional new adaptors for the PF4/5 coil hard BUS reconnection, design drawings, and to analyze the results of the coil BUS reconnections.

Research (S. Kaye):

NSTX-U researchers N. Bertelli, S. Shiraiwa, and M. Ono of PPPL attended the virtual 9th QUEST workshop (Kyushu University, Fukuoka, Japan) on related spherical tokamak radio frequency startup and sustainment plasma research Jan. 25-27. Shiraiwa gave a presentation entitled, “Recent Development in Petra-M FEM Framework and Application to Tokamak Experiments.” Bertelli gave a presentation entitled, “High Harmonic Fast Wave Simulations in NSTX-Upgrade by Using the Petra-M FEM Framework.” Finally, Ono gave a presentation entitled, “Multi-Mode Excitation in Radio-Frequency Heating and Current Drive.”

ITER PROJECTS (H. NEILSON)

Motional Stark Effect — MSE (A. Cohen):

PPPL Engineer B. Linn presented results of a mirror thermal deformation study intended to support an assessment of cooling requirements for the mirrors. The study modeled a mirror of bi-conic geometry subjected to heat loading and thermal ratcheting expected in its plasma-facing location in an ITER diagnostic port. The deformations caused by this thermal loading were shown to result in a slight tilt and a slight increase in the bi-conic radii with a residual departure from bi-conic of +/- 0.01 mm. It is planned that the results of the deformation analysis will be analyzed by the Laboratory’s design partner using an optical design code. However, the team judged that the impact on performance, though not negligible, could be corrected either by optical methods or by modifying the structures, such that direct cooling of the mirror itself could be avoided. The optical analysis is expected to confirm that conclusion.

ITER CAD team leader M. Messineo presented the updated MSE geometry in Equatorial Port 01 using the latest optical path calculation provided by IO. A previous line of sight issue was shown to be resolved. Additional updates to space reservations and other

interfaces were made, with the aim of enabling the EP01 team to freeze MSE interfaces in preparation for a planned final design review.

Low Field Side Reflectometer — LFSR (A. Zolfaghari, S. Shirey):

Progress toward closeout of the final design review of the in-vessel antenna assembly continued with the closure of several of the Category 1 and 2 chits raised at the review. Also, revisions to several deliverable documents, namely a Port Integrator Site Assembly Plan, Port Plug Test Facility plan, and Electromagnetic Analysis Report, have been submitted. Engineering analysts W. Wang and W. Syed have updated the responses to thermal and structural loads on the system to be consistent with recently updated loads and design details. Post-processing to determine margins against design criteria is in progress.

The LFSR manufacturing team has located a domestic source for cutting fluid compliant with ITER requirements for equipment installed within the torus vacuum. The availability of an approved material makes it possible to proceed with development of machining and gun-drilling procedures applicable to the ITER hardware deliverables. In addition, new methods in ultrasonic testing indicate that a gap observed between the copper-chromium-zirconium bushing and block after bushing expansion may be an artifact of the cross-sectioning method used in the inspection process.

Electron Cyclotron Emission — ECE (G. Paraiso):

The team is revisiting the design of a so-called compliant seal, which provides a flexible gas barrier connecting the vacuum window with the ex-vessel microwave transmission system being developed by INDA. However, a displacement compensation/alignment unit being designed by INDA would keep the input waveguide aligned with the window. The function of accommodating vacuum vessel movement appears to be redundant between these two components. Since the two components also have other functions, it was agreed to form a joint working group to collaborate in defining a design solution that addresses both U.S. and INDA requirements. The split of design responsibility will be clarified once a design solution has been defined.

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ITER & TOKAMAKS (R. NAZIKIAN)

DIII-D (B. Grierson):

Research:

DIII-D results advancing the development of real-time deposition of wall coatings by powder injection were reported by two contributions at the PSI-24 conference. A. Bortolon delivered an invited presentation focused on DIII-D experiments showing the effectiveness of the technique in controlling wall particle sources, analysis of samples coated with boron-rich films, as well as integrated modeling in axisymmetric geometry allowing the first prediction of film deposition rates. The research was carried out in close collaboration with PMI experts from UCSD, LLNL, UTK and UI-UC. F. Effenberg presented simulations of impurity transport with a full 3D description of the DIII-D plasma edge and scrape-off layer with EMC3-EIRENE to quantify, for the first time in a tokamak, the toroidal asymmetries of the film deposition at the divertor targets, associated with the toroidal localization of the boron particle source.

A continuation of the DIII-D 210-degree co/counter off-axis neutral beam (CCOANB) checkout experiment was led this week by S. Haskey, B. Grierson, and collaborators from GA and UC-Irvine. Data from the experiment will be used to assess the neutral beams injected and absorbed power using neutron measurements of beam blips and pulses from the various sources, and comparing them with those simulated by TRANSP with NUBEAM. The 210-degree beamline was oriented in the counter-current direction for this experiment, and a voltage scan was performed to determine the ability of the 210-degree counter-Ip beam to balance the co-Ip torque from the off-axis 150L (tangential) beam.

International PMI and Liquid Metal PFC Concept Development (R. Maingi & A. Diallo):

R. Maingi and A. Khodak presented dual short seminars for University of Wisconsin-Madison students and staff: “Status and progress in the domestic liquid metal plasma-facing component design program” and “MHD drive of liquid lithium in plasma-facing components,” respectively. Maingi’s talk summarized progress from the domestic liquid metal plasma-facing component design program, while Khodak’s talk showcased calculations on the concept of liquid lithium dual usage as a coolant and plasma-facing surface.

PPPL researchers G.Bodner, R.Lunsford, and A.Diallo led a remote session with Oak Ridge National Laboratory and CEA collaborators to further assess the impact of boron powder on the performance of WEST plasmas. This additional run session built on the original experimental goal to improve the wall conditioning of the PFCs in order to

access H-mode. In this session, the IPD dropped boron powder in discharges with significantly larger LHCD power (4.5 MW) than previously run. Low-Z line radiation (D, C, O, and N) were observed to decrease during boron powder injection, while W-I line radiation was shown to slightly increase. One shot showed a possible confinement improvement with powder injection, suggestive of an L-H transition.

R. Maingi hosted a periodic liquid metal PFC concept development management group meeting, discussing desirable experiments to run on the Liquid Metal eXperiment that connect to open questions in the PFC design calculations being done for FNSF.

ADVANCED PROJECTS (D. GATES)

Stellarators (D. Gates):

F. Nespoli presented a poster at the 24th PSI (virtual) conference titled, “First Impurity Powder Injection Experiments in LHD.” The poster reports on the first set of experiments performed on LHD using the PPPL developed impurity powder dropper, where the response of the plasma to the injection of boron and boron nitride powder has been characterized.

R. Lunsford delivered a remote seminar at the weekly W7-X science meeting entitled, “Characterization of injection and confinement improvement through impurity-induced profile modifications on the Wendelstein 7-X stellarator.” This talk covered the boron carbide powder injection experiments which were undertaken at the end of the last W7-X experimental campaign and specifically focused on the surprising elevations in core ion temperature and stored energy observed after powder injections. The present working theory, corroborated by measurement and similar results from frozen pellet injection, appears to suggest that the steepened edge density gradients which result from powder injection are stabilizing to ITG scale turbulence which in turn reduces anomalous transport allowing greater equilibration of electron and ion temperatures in these ECH-only heated discharges. The possibility for further clarifying experiments to be performed during the upcoming W7-X operational period 2.0 was also discussed.

The Laboratory is a partner with Oak Ridge National Laboratory in a project to deliver a Continuous Pellet Fueling System (CPFS) for Wendelstein 7-X. On Jan. 29, the project passed an important milestone with a successful final design review (FDR) of the mechanical systems, namely the injector and support stand, as well as their integration in the W7-X facility. The PPPL fabrication team of M. Safabakhsh and J. Philip described the design of the support stand, including recent structural enhancements based on analysis by PPPL’s D. Bishop. The review panel, chaired by PPPL’s T. Stevenson, found the design to be in compliance with system requirements and ready to move to

fabrication. A second FDR, covering the instrumentation and control (I&C) aspects of the project, planned for March, will complete the final design of the system.

COMPUTATIONAL SCIENCE (W. DORLAND)

TRANSP (F. Poli):

In collaboration with the PPPL development team, the JET TRANSP team led by Z. Stancar has successfully validated the first set of TRANSP and BEAST inter-shot interpretive simulations of mixed hydrogen-tritium plasmas performed at JET in December. Five discharges aimed at studying the L-H transition in H/T plasmas have been modelled in an attempt to verify the T(T,2n)4He cross sections implemented in TRANSP, to validate the computed neutron rate emission and to determine the concentration of residual D in the vacuum vessel. With almost 100 runs completed it has been found that using the newly implemented D. Coster IPP TT cross section fit the neutron rates measured with ex-vessel fission chambers were successfully reproduced with TRANSP. The validation effort will continue with TRANSP analyses of plasmas heated with the neutral beam injection system using tritium beams, supported by experiments planned to be performed within JET's C40 T campaign.

THEORY (S. HUDSON)

A paper by A. Wright, N. Ferraro, S. Hudson et al. titled, “Predicting nonresonant pressure-driven MHD modes in equilibria with low magnetic shear” was published in *Physics of Plasmas*: https://doi.org/10.1063/5.0032489. Selected as a featured article, the work introduces a simple three-step procedure for predicting nonresonant modes in low-shear equilibria using a continued fraction representation of the safety factor/rotational transform value of interest (in this case, the q on-axis).

N. Lopez and I. Dodin wrote a paper titled, “Metaplectic geometrical optics for modeling caustics in uniform and nonuniform media” that was published in *Journal of Optics*: https://doi.org/10.1088/2040-8986/abd1ce. This paper presents a general formulation of so-called metaplectic geometrical optics (MGO) for scalar fields. Unlike traditional geometrical optics, MGO is well-behaved at caustics and allows calculating the corresponding wavefields without invoking the full-wave description. Applications to two-dimensional fold and cusp caustics are presented as examples.

C. Clauser and S. Jardin wrote a paper titled, “ITER cold VDEs in the limit of perfectly conducting walls” that was published in *Physics of Plasmas:* https://doi.org/10.1063/5.0037464

F. Ebrahimi attended an the MPPC workshop and presented a talk at the reconnection breakout session entitled, “Plasmoid-mediated reconnection during peeling-ballooning ELMs.” F. Ebrahimi also attended the FLARE workshop on Jan. 15.

COMMUNICATIONS & PUBLIC OUTREACH (A. ZWICKER)

Communications (L. Bernard):

The Office of Communications posted three press releases to the PPPL website. The first reported that PPPL has been awarded three new public-private contracts to facilitate harnessing on Earth the fusion that powers that sun and stars. The awards under the DOE’s recent Innovation Network for Fusion Energy (INFUSE) program represent three of the 10 second-round INFUSE partnerships designed to speed the development of fusion as a virtually limitless source of energy for generating electricity.

The second reported on “The Renaissance of the Stellarator,” the first Ronald E. Hatcher Science on Saturday lecture presented by D. Gates that took place on Jan. 9. More than 300 people from New Jersey and around the world, including Japan, Germany, and France, attended the virtual lecture, which was the first time a Science on Saturday event was held online.

The third reported on research by F. Ebrahimi into a new type of plasma rocket thruster based on physical phenomena that occurs on the surface of the sun and other stars. The device would apply magnetic fields to cause particles of plasma to shoot out the back of a rocket and, because of the conservation of momentum, propel the craft forward. Current space-proven plasma thrusters use electric fields to propel the particles.

These stories were also posted to the *Newswise* and *EurekAlert* press release distribution services.

L. Bernard participated remotely in the National Laboratories Chief Communications Officers (NLCCO) monthly meeting on Jan. 28.

DIRECTOR’S OFFICE (S. COWLEY)

M. Zarnstorff, J. Menard, and S. Cowley participated virtually in the Max Planck Princeton Center (MPPC) workshop Jan. 19-22 and Jan. 25-26.

S. Cowley, M. Zarnsorff, and J. Menard participated virtually in the Nuclear Regulatory Commission (NRC) meeting on Jan. 26. The purpose of the meeting was to provide an opportunity for external stakeholders and the NRC staff to exchange information on the

NRC's development of a regulatory framework for the possible commercial deployment of fusion energy systems.

F. Jenko from Max Planck Institute of Plasma Physics presented a virtual colloquium titled, "When will we be able to predict plasma confinement in fusion devices?" on Jan. 27.

This report is also available on the following web site:

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