Weekly HIGHLIGHTS

PPPL PRINCETON PLASMA PHYSICS LABORATORY

U.S. DEPARTMENT OF ENERGY

The PPPL Highlights for the week ending August 26, 2016 are as follows:

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

Steady State Electric Network (SSEN):

Uninterruptible Power Supply (UPS) system and DC Distribution: Contract award recommendations were made for both procurements. Best and Final Offers were requested and final negotiations are underway. Various activities that need to reach closure before contract signature include DOE review, ITER approval of final version of specification, and ITER approval of technical documentation. The cost basis for the Arrangement to transfer the battery bank procurement to ITER has now been documented and sent to ITER for approval. Once the contracts are signed, and the cost basis is approved, the Arrangement can be signed. The objective is to sign the two contracts and the Arrangement prior to the end of FY 2016 so that US ITER can obligate the funds.

Power Transformers: Shipment of Lot 1 and Lot 2 oil-filled units (8 @ 35MVA and 4 @ 7MVA) from the Schneider Electric factory near Istanbul, Turkey has been delayed again until next week as plans for loading/transport are being finalized. Note that each 35MVA unit, and perhaps each 7MVA unit, will require a separate truck so there may be as many as 12 individual trucks involved. Also, ITER has now indicated that the temporary oil retention set up during storage will not be ready until September 12, so we need to coordinate shipments so as not to arrive before then.

6.6kV Switchgear: The remaining 110 cubicles in Lot 3 and 4 from the Schneider Electric factory in Manisa, Turkey, were shipped and are due at their destinations on August 30-31. The Lot 3 delivery destination is the ITER site but Lot 4 is being delivered to a EU factory in Spain for installation in prefabrication substation containers.

Diagnostics:

A total of 10 persons from the ITER Fabrication Department will travel to the US ITER office in Oak Ridge for a Red Team Review, August 30 - September 2. This includes the WBS Team Leaders, Project Control Officer, and Cost Account Managers (CAMs) for the various WBS elements of SSEN and Diagnostics. It has been announced that the next review, under the auspices of the DOE Office of Project Assessment (OPA), will take place week of November 14. The Red Team Review prepares the team for the OPA review, which aims to achieve CD-2/3 approval for the US ITER Project.

Several members of the team attended the TOFE conference in Philadelphia, presenting papers and posters on US ITER Diagnostics and Port Plug engineering progress. The posters presented were: A. Jariwala, "Upper Port Plug 14 Diagnostic Shielding Module (DSM) Design"; R. Feder: "Nuclear Analysis in Support of USITER Upper Port 14 Integration and the Upper Port Wide Angle View Visible-IR Camera System"; A. Khodak: "Parametric Thermal and Flow Analysis of ITER Diagnostic Shield Module"; M. Smith, "Electro-Magnetic Analysis of the ITER Upper Visible Infrared Wide Angle Viewing System"; Ali Zolfaghari: "General Overview of the ITER Low Field Side Reflectometer diagnostic system"; Wenping Wang: "Heat Loads & Cooling Requirements of Diagnostic Shielding Module of ITER Port Plug"; H. Zhang: "Dynamic analysis and inertia load of ITER equatorial port plug EPP9 DSM2".

Low Field Side Reflectometer (LFSR): Progress continues in the development of a Field Programmable Gate Array-Based Signal Processing system for LFSR. A Zoom meeting was held on July 8 to discuss Field Programmable Gate Array (FPGA) projections to ITER with M. Bobrek (ORNL) and A. Zolfaghari (PPPL) also participated. The main outputs of the meeting were that: (a) Miljko aims to complete a first draft of an ITER FPGA design report by September. This document is intended to describe the preliminary Design Review plan for the use of FPGA data processing for the LFSR system, using presently available target National Instruments (NI) hardware. (b) It is only necessary to describe how the present Simulink algorithm and design will be ported to the NI LABVIEW environment, rather than actually performing such a port. Subsequently, the report entitled "Test of the FPGA Real-time Reflectometer Phase Analysis System on the DIII-D Tokamak" (304171-R00006A) was reviewed and prepared for release.

A kickoff meeting was held between UCLA and Virginia Diode, Inc. (VDI) on July 7 to discuss overall planning and technical details for the microwave source/receiver upgrade. A number of technical issues were identified for resolution, while a major development was that VDI stated that the 14 week quotation to complete the upgrade work is from the time the design is finalized, not the placing of the order. UCLA subsequently provided VDI with information requested at the kickoff meeting, and Tony Peebles iterated multiple emails and calls with VDI. The major outstanding issue still to be addressed is to define a receiver architecture, which can adequately withstand not just electron cyclotron heating and plasma emission, but also reflections of the source itself.

Two approaches to enable Frequency Modulated Continuous Wave (FMCW) tests in the near-term, without having to wait for the upgraded VDI sources, were investigated. The first option is to add a receiver system to the un-upgraded VDI-W-band source. This would be a simple and limited approach, to enable us to take a first look at FMCW data. Due to the step-wise nature of the present frequency sweep, the measurements would have to be performed at a very high sweep rate (~few μs), where the present VDI filter circuit has an effect. The second option is to add a receiver system to the synthesizer/frequency-multiplier based source at present in use on the microwave test stand at DIII-D. We have the necessary components to do this. What is unclear is how fast the synthesizer source can be frequency swept (documentation is unclear). It will probably require an experimental test to evaluate if this option will work.

Motional Stark Effect (MSE): SimMSE, a code that models the MSE diagnostic on ITER, is being reconfigured by the Nova Photonics team to analyze the MSE-LS systematic uncertainties due to spatial uncertainty parameters. Initial parameters to be studied include sensitivities of the

LS measurement to uncertainties in the neutral beam vector direction and magnitude (i.e. beam energy), as well as the MSE sight-line vector. Results will show how accurately the MSE-LS will need to be spatially calibrated to produce useful constraints for equilibrium reconstruction. These results will be continued through a virtual in-situ calibration, where MSE spectra from multiple channels will be used to best constrain the beam vector using techniques similar to those used at DIII-D (Chrystal, Burrell, Grierson, Pace RSI 86(2015)103509). This exercise seeks to provide tolerances for optomechanical design, but it will not include those designs. It would be highly useful to begin conceptualizing MSE-LS optics designs that can achieve very high spatial accuracy and methods to calibrate MSE-LS sightline vectors in-situ to account for movement after installation.

MSE vacuum window testing has started at Nova Photonics. The polarimeter to measure the stress-induced birefringence has been assembled and tested. A setup using a 6-way cross with standard 8" conflats has been setup. Windows have been tested at atmospheric pressure and under vacuum with a small change is retardance observed. Temperature testing to about 95º C has been completed. Very large retardance changes have been observed with the borosilicate window.

Electron Cyclotron Emission (ECE): University of Texas team made significant progress in defining the heater for the Calibration Hot Source. Analytical and experimental investigation showed that inconel heater cannot provide sufficient energy to get the front surface of the emitter to required 700C due to heater temperature limitation. Alternative off the shelf Molybdenum Heater was found, and will be acquired for testing. This heater can reach much higher temperatures, and will be able to satisfy Hot Source requirements with significant margin. Testing of the piezo motor is continuing at PPPL with experimental setup assembled and motor is tested at room temperature for performance and initial outgassing in vacuum.

Equatorial Port 9 Integration and DSM Engineering: Important progress was made this week on the TIP front mirror prototype design, providing definition for mirror installation in DSM3 optics cassette. Mirror thermal analysis will soon allow cassette coolant design to complete.

Toroidal Interferometer and Polarimeter (TIP): The implications have been assessed and a strategy has been developed to deal with the possible scenario that BaF2 windows are abandoned and chemical vapor disposition (CVD) Diamond windows are chosen by IO for TIP. CVD diamond has several properties that impact the current TIP design. It has large absorption in the ~2.5-7 micron range, large index of refraction (n~2.4) so large reflection, limited aperture size, and less than desirable optical product specifications (primarily flatness / transmitted wavefront distortion). The primary impact of these is on choice of the vibration compensation wavelength. If the decision is made to abandon BaF2 windows, the recommended course of action would likely be to switch the vibration compensation wavelength (currently 5.22 microns in the TIP prototype and planned to be 4.6 microns on ITER) to an 8 micron quantum cascade laser (QCL). This would be a relatively plug-and-play solution using the current design with the primary drawback being a density noise floor about twice that of the current system. Due to relatively large index of refraction, CVD diamond would require anti-reflective coatings that can tolerate the ITER environment. After DIII-D prototype testing, the plan is to purchase a 4.6 micron QCL and optics for a 4.6 and 10.59 micron TIP then re-install the components in the beam path lab for testing. Instead of 4.6 microns, an 8 micron QCL and associated optics would be purchased. It is also pointed out that a CVD diamond window essentially eliminates the

possibility of a CO2 laser dispersion interferometer (DI) – irrespective of wavelength choice. Diagnostic windows that have been certified for ITER nuclear operation are being completely designed and furnished by the IO so it is important for the USDA to work closely with the IO on a solution.

NSTX-U (M. ONO):

Several NSTX-U and ST researchers and engineers gave oral and poster presentations at the Topical Meeting on the Technology of Fusion Energy (http://tofe2016.ans.org/) held August 21-25, in Philadelphia, Pennsylvania at the Sheraton Philadelphia Society Hill. NSTX-U/ST-related invited talks included: "Overview of Initial Operation on NSTX-U" by D. Battaglia, "Studies of Next-Step Spherical Tokamaks Using High-Temperature Superconductors" by J. Menard, "ST-Based Fusion Nuclear Science Facility: Breeding Issues and Challenges of Protecting HTS Magnets" by Laila A. El-Guebaly (University of Wisconsin), and "Boronization System for the NSTX-Upgrade Fusion Device" by D.Cai. Poster presentations included "Thermal and structural performance evaluation of the NSTX-U high-Z divertor" by A. Brooks, "NSTX-U Second Neutral Beam Relocation" by N. Atnafu, "NSTX-U Bake-Out Simulations and Evaluations" by P. Titus, and "Design and operation of the electrical noise suppression system for CHI on NSTX and NSTX-U" by Z. Gao.

Steve Sabbagh and Young-Seok Park of Columbia University ran two experiments on the KSTAR superconducting tokamak in Daejeon, Korea entitled "Stability Limits in Maximum Normalized Beta Plasmas with Steady-state Profiles, Moving Toward Lower q95 Operation", and "Variation of NTV torque: Distinct torque profiles and NTV offset rotation". Earlier high betaN operation that was curtailed by rotating MHD activity was extended to 3 seconds by a delayed onset of the mode. Higher ion temperature (near 4 keV) was run in the NTV experiment compared to 2015, which demonstrated significantly stronger n = 2 non-resonant plasma rotation damping, and braking by using the n = 1 "non-pitch-aligned" configuration now eventually yielded resonant braking, and locking. Therefore, use of this n = 1 configuration to produce stronger non-resonant core NTV is susceptible to locking.

NSTX-U researchers attended and presented invited talks at the US-Japan Compact Toroid Workshop (http://www.physics.uci.edu/US-JAPAN-CT2016) in Irvine, California (August 22-24). Walter Guttenfelder presented "Transport at high beta in spherical tokamaks" which provided an overview of the unique stability characteristics of the ST configuration, NSTX transport and turbulence observations & validation efforts, and a brief summary of initial NSTX-U operations. Roger Raman (University of Washington) presented "Overview of transient CHI plasma start-up research in NSTX-U" which provided an overview of coaxial helicity injection in NSTX, best results achieved, as well as upgrades that will enhance CHI capabilities in NSTX-U.

Disassembly and removal of equipment from the NSTX-U upper umbrella was completed, and the failed PF1aU coil has been removed from the test cell. Another round of PF1aU electrical insulation, resistance, and inductance measurements have been taken as a baseline, and the coil is being prepared for off-site radiography. Setup of the coil winding facility continues. On the vessel, a contaminated through-bolt on the upper ceramic break was found to be the cause of a variable inner to outer vacuum vessel electrical leakage path. Trimethylboron inventory has

been removed from the TMB system, and sulfur hexafluoride is being reclaimed from the neutral beam power systems. Lockout/Tagout of NSTX-U vessel hazardous energy sources is underway per procedure in preparation for a vessel entry next month. The neutral beam-lines are being pumped, purged, and vented in preparation for the removal of the calorimeter assemblies for maintenance. Also this week, on-site training on the application of Micro-Optics Fiber Bragg Grating systems for shear stress measurement was held.

ITER & TOKAMAKS (R. HAWRYLUK):

DIII-D (R. Nazikian):

Shaun Haskey and Matt Lanctot (GA) have collaborated on main-ion rotation evolution for n=2 error field penetration experiments in L-mode plasmas. The profiles clearly show the main ion toroidal rotation collapses at a critical applied error field, and a subsequent recovery of the toroidal rotation after the applied error field is removed. During the locked state, non-monotonic strongly sheared rotation profiles are observed between the 2/1 surface and the plasma edge. The sheared toroidal rotation of the main ions near the edge may be due to island interaction with ion orbit loss and its effect on the edge torque profile.

Madeline Vorenkamp, a PPPL student intern at GA, presented a poster at the TOFE 2016 conference this week entitled, “Impurity Granular Injector Upgrades on DIII-D”. In her role as an IGI team member at DIII-D she designed, fabricated, tested and optimized the granular counter system. The system allows for automated and hence rapid granule counting during an experiment and provides the session leader with timely information on the operational performance of the IGI.

ADVANCED PROJECTS (H. NEILSON):

This week, Dr. W. A.“Tony” Cooper arrived at PPPL to begin a 3-week working visit as part of the Laboratory’s LDRD-supported studies of turbulence-optimized stellarator configurations. Cooper, a veteran researcher with Switzerland's École Polytechnique Federale de Lausanne (EPFL), is the author of the MHD stability analysis code TERPSICHORE, a key component of the stellarator optimization suite. The aim of the project is to analyze a set of interesting quasi-axisymmetric (QA) and quasi-helically symmetric (QH) stellarator configurations and determine the degree to which their turbulent transport metrics can be improved through optimization, while simultaneously satisfying conditions for MHD stability. Turbulence optimization is a recent advance by theorists that offers the potential for quantum improvements in stellarator designs. The work by PPPL and collaborators such as Dr. Cooper will lead to tools that can turn promising concepts into feasible designs.

H. Neilson presented a plenary talk at the Topical Meeting on the Technology of Fusion Energy (TOFE) in Philadelphia. The presentation, "Toward Improved Stellarators: Future Directions for U.S. Research,” describes the need and the opportunity for the U.S. to make quantum improvements in stellarator end products (such as power plants) by taking advantage of recent physics and engineering advances. Experimental research on W7-X and a new initiative in theory, computation, and design are the primary thrusts for the next few years, while new U.S.

experiments will be needed to definitively test the potential of new concepts. The presentation is based on the work of a national team, which has been developing the strategy for U.S. stellarator research throughout 2016.

THEORY (A. BHATTACHARJEE):

On August 18, Zhi-Wei Ma (Institute for fusion theory and simulation, Zhejiang University, China) presented a theory seminar on effective resistivity in collisionless magnetic reconnection: The well-known physical mechanism for fast magnetic reconnection in collisionless plasmas is that the off-diagonal terms of the electron pressure tensor give rise to a larger electric field in the reconnection region. The electron pressure tensor fully associated with electron kinetic effects is difficulty implemented into the MHD model. In this talk, we try to use a simple equation $\boldsymbol{E} = \eta \boldsymbol{J}$ (where η is an effective resistivity) to illustrate the fast reconnection in collisionless magnetic reconnection. The physical mechanism and formulation of the effective resistivity are addressed.

Dr. Gorelenkov has visited the University of San Paulo (USP) as a part of USP-Princeton University Strategic Partnership Grant. The goal of this visit was to establish closer ties between PPPL and Institute of Fusion of USP (IFUSP) plasma physics group. This visit included two lectures given by Dr. Gorelenkov to IFUSP staff and students: Introduction to Energetic Particle Physics in Magnetic Fusion: classical confinement and equilibrium distribution function and collective effects. As a result of discussions with the researchers from USP, the planned workshop for 2016 at PPPL is moved to the second week of January 2017. Several USP researchers will come to Princeton to make their presentations at the workshop and have discussions with PPPL scientists. The USP delegation is expected to include Professor Ricardo Galvao and Artour Elfimov, students Vinicius Duarte (will be present at PPPL by that time for a long term visit), and Fabio Camilo de Souza. Two particular more specific topics were discussed in details with immediate implications to PPPL experiments on NSTX-U. The first topic is on the work V. Duarte is doing at the moment together with Dr. Gorelenkov. The second topic is on the calculations of the low-frequency geodesic acoustic mode (GAM); like solutions in the presence of energetic beam ions and the instabilities caused by EPs. Professor Elfimov and his student, Fabio Camilo de Souza, will focus on this topic in 2017

On August 25, Jason TenBarge (U Maryland) presented a theory seminar on dissipation and intermittency in gyrokinetic turbulence and beyond: Turbulence is a ubiquitous process in space and astrophysical plasmas that serves to mediate the transfer of large-scale motions to small scales at which the turbulence can be dissipated and the plasma heated. In situ solar wind observations and direct numerical simulations demonstrate that sub-proton scale turbulence is dominated by highly anisotropic and intermittent, low frequency, kinetic Alfvenic fluctuations. Recent work on the dissipation of Alfvenic turbulence observed in gyrokinetic simulations was reviewed, with a discussion of the coherent structures and intermittency associated with the turbulence, which suggest a non-local and non-self-similar energy cascade. Tull Eulerian Vlasov-Maxwell code, Gkeyll, being developed at Princeton and the University of Maryland was described. The abstract and slides when available, are online here.

A Theory Department Research Review Seminar was given by Michael Maul, who talked about recent Report “Frontiers of Plasma Science” on, August 26. This report is intended to inform

FES in planning and executing its strategic vision for the FES stewardship of the Plasma Science Frontiers activities. The preliminary draft of Report of the Panel on Frontiers of Plasma Science (PDF, 3.29 MB) is now available at https://www.orau.gov/plasmawkshps2015/report.htm. Fundamental plasma physics has never had the benefit of a research needs workshop and we believe that the community of researchers would greatly benefit from a survey of the current state of the art, as well as from formulating a cohesive vision of the future horizons we can aim towards. Our goal is that the Plasma Science Frontiers report will be of benefit to both the community and all funding agencies interested in plasma science, not just the Department of Energy. Furthermore, our report will serve as a starting point for the next NRC decadal survey of plasma science (Plasma 2020). ”

M. Churchill travelled to Lawrence Berkeley National Laboratory to attend NERSC Data Day, a two-day event designed to bring together researchers who use, or are interested in using, NERSC systems for data-intensive science. Attendees heard talks from NERSC data experts, and spent a morning doing hands-on work with Spark, Python, and deep learning algorithms. Michael presented a poster entitled “Analyzing Large Data Sets from XGC1 Magnetic Fusion Simulations using Apache Spark”.

BUSINESS OPERATIONS (K. FISCHER):

The Accounting Division submitted the annual Improper Payment and Recapture Audit report to DOE-CH and DOE-PSO on August 25. Payment reporting sites were required to provide actual FY 2015 improper payment and payment recapture information for vendor/subcontract, travel and payroll payments. PPPL continues to maintain a low improper payment rate and a high recapture rate. Improper payments for FY 2015 were .032% of total payments with a 100% recapture rate.

COMMUNICATIONS & MEDIA RELATIONS (L. BERNARD):

A story by J. Greenwald on a new center to understand and mitigate runaway electrons that may pose a challenge for ITER was the number one feature on the DOE Office of Science web page Science Headlines on August 24. The DOE also retweeted the PPPL tweet about the new center, which is co-led by D. Brennan of PPPL and Princeton University.

Greenwald reported, wrote and posted complementary news releases based on J. Menard's paper on spherical tokamaks as models for next steps in the development of fusion energy.

Greenwald also worked with E. Starkman and graduate student S. Philippe on a video for September publication of a paper in Nature Communications on the zero-knowledge verification of nuclear weapons, co-authored by R. Goldston.

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