Weekly HIGHLIGHTS

PPPL PRINCETON PLASMA PHYSICS LABORATORY

U.S. DEPARTMENT OF ENERGY

The PPPL Highlights for the week ending September 16, 2016 are as follows:

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

Steady State Electric Network (SSEN):

Uninterruptible Power Supply (UPS) system and DC Distribution: Contracts and supporting materials have all been prepared and transmitted for approval prior to signature. The UPS package requires DOE approval, whereas the DC Distribution package is below the threshold. Our objective is to award the contracts before September 30.

Arrangement for UPS + DC Distribution Battery Banks and for LV Distribution & Sub-Distribution Panels: An "Arrangement" will be used to transfer these items for future procurement by the ITER Organization because the storage life of the battery banks is limited and because the distribution panel requirements are not yet mature. The Arrangement document has been prepared and a memo establishing the cost basis has been submitted for approval by the ITER Organization. Our objective is to sign the Arrangement as soon as the contracts for the UPS and DC Distribution are signed.

Power Transformers: Shipment of Group 1 and 2 transformers (that comprise shipping lots number one and number two) from the Schneider Electric factory near Istanbul, Turkey, was targeted to begin on September 26 but will probably slip again due to logistics complexities and holiday closure of the factory in Turkey this past week. The transformers accessories will be shipped separately from main transformer bodies but must follow the same modality and route and customs points, according to Turkish regulations. The Group one transformers will be shipped one per lowboy truck (total eight trucks for eight units), and two Group two transformers will be shipped per standard truck (total two trucks for four units), and the accessories will be shipped in trucks following the same routes. Packing lists and pro forma invoices must be prepared for each truck by the supplier and approved by all parties before shipment. Trucking will be scheduled so that all main bodies arrive at ITER site in a single day, and all accessories on another day.

DIAGNOSTICS:

Upper Port Wide Angle View Vis-IR Cameras (UWAVs): A paper entitled "Status of the Upper Wide Angle Viewing System R&D and Design Efforts for ITER" was presented at the SOFT conference. Preliminary design of the UWAVs Intermediate Optic Tube (IOT) continued. Design efforts have been focused on optimizing the mirror assemblies for efficient cost effective

manufacturing, field of view performance, assembly clearances, and stability. Other assemblies have been re-designed to reduce assembly mass and promote fabrication ease.

Low Field Side Reflectometer (LFSR): Assembly of the LFSR Gaussian Telescope test rig has started this week. The key step was finding available lab space at PPPL. Once the test rig is assembled the alignment-maintenance capabilities of the Gaussian telescope mechanism will be tested. The telescope features a novel mechanical system that maintains optical alignment while flexing to accommodate the relative motion between the port plug and the building during ITER operations and bake-out.

Electron Cyclotron Emission (ECE): Andrei Khodak and Gary Taylor visited ITER September 12-14 to discuss various aspects of the ITER electron cyclotron emission (ECE) diagnostic design and its important application for detecting neoclassical tearing mode (NTM) activity to provide a sensor for the system to suppress NTMs by EC heating. They had wide ranging, productive, discussions with members of the ITER diagnostics, plasma operations and control, and EC heating groups that covered the design of the ECE primary vacuum window, the Diagnostic Shield Module in the Port Plug, neutronics modeling, planning for a peer review of the hot calibration source development at ITER early next year, the viability of an inline ECE diagnostic in the EC launchers to enhance NTM detection, and the ability of the ECE diagnostic to support low field H/He plasma operations at axial toroidal fields down to 1.8 T.

Diagnostic RGA (DRGA): The DRGA team met this week to discuss a re-plan for the DRGA project. The new plan will be organized into four key areas. The first work package is engineering and design for the ITER First Plasma DRGA hardware, which is comprised of some vacuum flanges for sealing DRGA sampling ports. The second work package will be the plans for design and testing that will bring the DRGA instrumentation set up to a Final Design status. This includes developing radiation and magnetic hardened options as well as an alternative to the Optical Penning Gauge instrument. The third phase or work package is all of the integration, design engineering and analysis for the two port-based installations in Lower Port 12 and Equatorial Port 11. This phase will be delayed in the new US ITER baseline plan until all interfaces are well understood and reviewed at ITER. The fourth work package covers all the I&C, CODAC and ITER software design and fabrication. A detailed new budget and schedule estimate is underway and should be complete by mid October.

Upper Port 11 and 14 Integration and DSM Engineering: Existing shorter DSM support frame is analyzed for the EM loads. Result shows the frame stresses are within allowable levels. To support all pipes from back of FEOT to the closure plate this frame is increased in length. Second round of Analysis will be performed on the longer frame for the stresses and to spec out bolt size to attach it to PPS. First draft of Remote handling documents for UP11 is submitted for iDocs to file it into IDM.

Equatorial Port 9 Integration and DSM Engineering: Yuhu Zhai presented the paper "Development of Load Specification for the design of ITER diagnostic system and port integration" at the SOFT conference in Prague this week.

Toroidal Interferometer and Polarimeter (TIP): Reports have been drafted to describe the mechanical design and thermal distortion for the TIP in-vessel optics. Molybdenum corner cube

retroreflectors that are radiatively cooled, and Moly turning mirrors that are clamped to water-cooled stainless baseplates are described in detail in these reports.

Core Imaging X-Ray Spectrometer (CIXS): A second round of electromagnetic testing of a Core Imaging X-ray detector in the D-Site FCPC testing facility was completed this week. Expected magnetic field strength that is 3.44T at 12KA was achieved and quality data was recorded. The whole effort was successful due to great teamwork, internally (PPPL, between divisions) and externally (we and vendor), which ensures the mission completed within the timeline and budget. The results from the test are excellent and the (front end) x-ray detector survived experiencing fields as high as 3.3 Tesla and maximum time varying fields of 3T/sec. The images of the knife-edge shadow before and after each of the 14 shots are pretty much identical.

NSTX-U (M. ONO):

The paper "Massive Gas Injection Valve Development for NSTX-U", by the University of Washington team members, R. Raman, G.J. Plunkett, and W.S. Lay, IEEE Transactions on Plasma Science, Vol. 44, Issue 9, September (2016), DOI10.1109/TPS.2016.2565658 was published on-line, here. The paper summarizes the design and off-line experimental results from the operation of a "ITER-Type" MGI valve. Two of these valves have now been commissioned on NSTX-U. The paper also describes operation of the valve in 1T ambient magnetic fields.

The NSTX-U Team Meeting was held on September 15 at PPPL. The NSTX-U team was updated on the on-going outage activities and the near and longer term plans. The meeting material is available here.

Lockout / Tagout of all hazardous energy sources in preparation for the NSTX-U vacuum vessel entry were completed this past week, and the Neutral Beam #1 torus duct and spool piece were removed. Pre-Job briefs and Health Physics reviews were then completed before issuing the Confined Space Permit for the initial vessel entry for inspections and photographs. In-vessel diagnostic calibrations will begin this coming week. Radiography of the damaged PF1aU coil has been completed, and radial locations of possible voids in the conductor have been identified. The coil is in our shop being prepared for dissection and borescope inspections as part of the ongoing forensics. Engineering plans and schedules for the removal of the NSTX-U center column to allow for the redesign and replacement of both the PF1a Upper and Lower coils are now in place. Coil mandrels are being fabricated, and the required coil conductor is on order. Set-up of the coil winding facility continues. Also this week, Field Coil Power Conversion (FCPC) systems were successfully used for magnetic testing of an ITER X-Ray Detector diagnostic. This FCPC test stand will be used later this year for power testing of the new PF1a coils.

The initial entry into the NSTX-U vessel was accomplished on September 16. Three tiles, four quartz microbalance crystals, and twenty-three Si witness coupons were retrieved for material analysis and a complete set of photographs of the vessel interior was taken.

On September 1, the final design review for the NSTX-U Bay-I and Bay-J divertor viewing resistive bolometers was completed. These systems will allow the radiated power from the lower divertor to measured. Long-lead time items have already been procured and following the

resolution of minor CHITs, fabrication of the new pinhole cameras will begin. These diagnostics are scheduled to be installed for the next NSTX-U operational campaign to support a range of boundary research activities.

On September 8 and September 9 the NSTX-U infrared video bolometer prototype was installed on Alcator C-Mod with the help of Jim Terry (MIT) and the C-Mod vacuum team. It was able to utilize an existing, installed IR camera at C-Mod and measurements were made during Ohmic and RF-heated H-mode and I-mode plasmas. Results will be useful in scoping future designs of IRVB technology for NSTX-U.

ITER & TOKAMAKS (R. HAWRYLUK):

DIII-D (R. Nazikian):

B. Grierson published an article "High resolution main-ion charge exchange spectroscopy in the DIII-D H-mode pedestal" in Review of Scientific Instruments (link). A new high spatial resolution main-ion (deuterium) CER system has been installed on DIII-D and is collecting detailed measurements of the main-ion temperature, velocity and density spanning the plasma boundary from the top of the H-mode pedestal into the scrape-off layer. This new capability will be used in upcoming experiments aimed at understanding momentum transport and intrinsic torque near the H-mode edge. A companion article by Shaun Haskey on the determination of the main-ion density in the steep gradient region has also been accepted by RSI, based on research presented at the 2016 High Temperature Plasma Diagnostics Conference.

B. Tang (Princeton University/PPPL) visited DIII-D and General Atomics, along with K. Felker (Princeton) and Julian Kates-Harbeck (Harvard) to present their recent work applying machine learning (ML) techniques to the prediction of major disruptions on JET. This visit also serves to kick off a collaboration with theorists and experimentalists at DIII-D that will demonstrate the portability of ML algorithms (i.e. the potential to train a predictive capability on one machine and apply it to another).

M. Churchill, A. Fil, R. Lunsford and R. Maingi visited GA to discuss collaborations. Churchill gave a talk at the BPMIC meeting highlighting the use of XGCa to simulate a low density, sheath limited DIII-D divertor. Lunsford gave a talk at the PedELM group meeting on impurity granule ablation modeling on NSTX-U and DIII-D, pointing to a near term study to analyze existing D3D data for a comparison of lithium, B_4C and carbon granule ablation rates and depths. Fil also gave a talk on the use of M3D-C1 to simulate lithium granule injection, ablation and ELM destabilization in DIII-D. All of the talks generated excellent discussion and useful feedback on next steps.

Dylan Brennan visited DIII-D this week to present recent results from the nonlinear modeling of coupled tearing modes using the NIMROD code. New features have been developed for imposing 3D boundary conditions to simulate island seeding and external magnetic perturbations in plasmas with both sheared and differential flow. In these simulations, the stability and rotation evolves rapidly toward a new saturated state similar to the phase-locked condition observed in experiment. Comparisons with analytic theory and DIII-D data are currently underway.

ADVANCED PROJECTS (H. NEILSON):

As part of the ongoing collaboration with Germany's Wendelstein 7-X (W7-X) stellarator program, S. Lazerson visited the project site in Greifswald to work on a number of topics. Lazerson conducted tutorials on the usage of STELLOPT to reconstruct W7-X plasma equilibria from experimental data. Max Planck Institute for Plasma Physics (IPP) colleagues, Drs. Gavin Weir, Tamara Andreeva, and Kian Rahbarnia, demonstrated the ability to run the STELLOPT code and begin equilibrium reconstruction of OP1.1 plasmas using data from Thomson Scattering, electron cyclotron emission, x-ray imaging crystal spectrometer, interferometry, and magnetics diagnostics. Discussions regarding the development of fast-ion loss detectors for W7-X identified resource requirements on both the PPPL and IPP sides of the project. A timeline for OP2 installation was outlined. Neutral beam benchmarking activities were presented showing good agreement among BEAMS3D, BBNBI, and IPP deposition codes. A fast ion loss benchmark was outlined among the ASCOT, VENUS-LEVIS, and BEAMS3D codes. Lazerson also participated in many discussion regarding turbulence in stellarators.

Dr. Masayuki Yokoyama of Japan's National Institute for Fusion Science (NIFS) visited PPPL for three days of discussions on stellarator physics and collaboration planning. It was agreed that a strengthening of collaboration activities between NIFS and PPPL is now timely. In the coming year, the Large Helical Device (LHD) at NIFS will enter a new regime with by operating with deuterium for the first time in its history. The recent startup of W7-X opens new possibilities for comparisons of data from these two world-class experiments, W7-X and LHD. It was agreed to support a new scientific exchange on stellarator transport physics analysis based on data obtained with x-ray imaging crystal spectrometer (XICS) diagnostics that PPPL has built and operated on both LHD and W7-X.

The W7-X divertor scraper project is in its final stages. All components for the mockup assembly have been delivered to the project site in Greifswald, Germany. Cleaning and bakeout of the graphite tiles for the two scraper units is now moving forward at the supplier's facility (Wall Colmonoy) of Cincinnati, OH, following a short delay for maintenance of the supplier's equipment. All other scraper components have been fabricated and inspected; they are at PPPL and are ready to ship to IPP as soon as the tiles are returned from the bakeout supplier.

THEORY (A. BHATTACHARJEE):

Allen Boozer (Columbia University) presented a theory seminar on relativistic electrons and magnetic reconnection in ITER. The abstract reads: ITER, the largest scientific project ever undertaken, "has been designed to prove the feasibility of fusion" energy. That mission could be compromised if the net current in the plasma were transferred to relativistic-electron carriers, which can result in great damage to the device. More than a hundred-fifty papers on the topic have appeared in the twenty years since it was realized that a sudden drop in the plasma temperature could cause such a transfer. The theoretical papers have focused on electron runaway when magnetic field lines remain confined to the plasma volume. Experiments and their simulation imply most magnetic field lines intercept the walls when a sudden drop in the temperature occurs. In simulations not all of the magnetic field lines intercept the walls. If these non-intercepting flux tubes survive until outer magnetic surfaces reform, an especially dangerous

situation arises in which the relativistic electrons can be lost in a short pulse along a narrow flux tube. Maxwell's equations imply the conservation of magnetic helicity during fast magnetic reconnections. Helicity conservation clarifies features, such as the spike in the plasma current during a thermal quench, and shows that a rapid, ~1ms, acceleration of electrons can occur. Magnetic reconnection can occur on a time scale of tens of Alfvén transit times either due to the formation of multiple plasmoids or as a result of the exponential sensitivity to non-ideal effects when an ideal evolution causes neighboring magnetic field lines to increase their separation exponentially with distance along the lines. In either case, magnetic flux tubes that had different force-free parallel currents $j_{/\!/}/B$ and different poloidal magnetic fluxes external to their surfaces can be joined in a fast reconnection. The differing parallel currents relax by Alfvén waves, and the change in the poloidal flux associated with a given enclosed toroidal magnetic flux is given by helicity conservation. Based on the observed time scale of current spikes, a few hundred toroidal transits are required to relax the $j_{/\!/}/B$ profile, which is consistent with distance along magnetic field lines implied by the speed of the electron temperature drop. Helicity conservation implies that although changes in the poloidal flux can occur on a time scale determined by the Alfvén transit time, the magnetic helicity and most of the poloidal flux can change only on a long resistive, $L/\mathcal{R}$, time scale. Rapid plasma terminations require plasma cooling. The potential for damage, the magnitude of the extrapolation from existing devices, and the importance of the atypical—incidents that occur once in a thousand shots—make theory and simulation essential for ensuring that relativistic runaway electrons will not prevent ITER from achieving its mission. The US DoE Office of Science has established a Simulation Center for Runaway Electron Avoidance and Mitigation (SCREAM) with a two-year funding of 3.9M$. The danger of runaway of electrons to relativistic energies can be avoided in magnetically confined fusion systems by making the net current the $j_{/\!/}/B$ sufficiently small. This is possible in the non-axisymmetric stellarator geometry though not in axisymmetric tokamaks, such as ITER.

COMPUTATIONAL PLASMA PHYSICS GROUP (S. JARDIN):

S. Jardin attended the Integrated Modeling Expert Group (IMEG) Meeting at ITER HQ this week. The TRANSP code has been made compatible with the ITER Integrated Modeling and Analysis Suite (IMAS) by means of translators developed by J. Chen and J. Carlsson that convert data between the ITER Data Structure (IDS) and the native TRANSP input of ufiles and eqdsk files, and convert the TRANSP netcdf output files to IDS files. Also, the NUBEAM neutral beam and fusion product package has been made into a IMAS Kepler component by M. Gorelenkova and can thus be used by other Kepler workflows.

ENGINEERING & INFRASTRUCTURE (L. DUDEK):

Fabrication and Operations Division (F. Jones, L. Dudek):

S/C Magnets R&D: A project progress meeting was held with prof. Yanagi from NIFS to discuss PPPL-NIFS collaboration on the development of high current HTS conductor and the NIFS high current HTS conductor test scheduled early next year. PPPL is providing engineering analysis for the 100 kA HTS conductor test sample and mechanical support design.

A paper titled "Finite element analysis of transverse compressive loads and cool down on an imperfect Nb3Sn wire" by Luc d'Hauthuille and Yuhu Zhai is submitted to Fusion Science and Technology for publication.

Latest results of PPPL and University of Geneva collaboration on the development of high performance superconductors for fusion magnets include two new talks given at the Applied Superconductivity Conference last week at Denver, Colorado. "High Performance Superconductors for Fusion Nuclear Science Facility", Yuhu Zhai, Charles Kessel, Christian Barth and Carmine Senatore. "Impact of voids on the electro-mechanical properties of Nb3Sn wires: a case study on bronze-route wires", by C. Barth, B. Seeber, A. Rack, C. Calzolaio and Y. Zhai.

BUSINESS OPERATIONS (K. FISCHER):

A renewal proposal was submitted to the Office of High Energy Physics for the project titled "Collective Processes and Nonlinear Dynamics of Intense Charged Particle Beams". The requested budget for the three-year period of performance is $1,022,000. The Principal Investigator is H. Qin.

A new Inter-Entity Work Order was executed with ORNL for first year PPPL funding of $1,381,744 for the Exascale Computing Project titled "High-Fidelity Whole Device Modeling of Magnetically Confined Fusion Plasmas". The Principal Investigator is A. Bhattacharjee. The total funding expected is $5.8 million covering the period through September 30, 2020.

Second year funding of $195,900 was received from NASA for the Strategic Partnership Project titled "Multi-Fluid Studies of Chromospheric Reconnection in a Partially Ionized Laboratory Plasma". The Principal Investigator is H. Ji.

Second year funding of $203,300 was received from NASA for the Strategic Partnership Project titled "Collective Research on the Role of Guide Field on Electron Dynamics and Waves During Fast Magnetic Reconnection". The Principal Investigator is H. Ji.

DIRECTOR'S OFFICE (C. AUSTIN):

On September 15, M. Zarnstorff attended the DOE Laboratory Operations Board meeting. The focus of this meeting is to find opportunities to improve effectiveness and efficiency in the National Laboratories.

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