Weekly HIGHLIGHTS

PPPL PRINCETON PLASMA PHYSICS LABORATORY

U.S. DEPARTMENT OF ENERGY

The PPPL Highlights for the week ending April 21, 2017 are as follows:

NSTX-U RECOVERY PROJECT (R. HAWRYLUK):

The twelfth and final NSTX-U Design Verification and Validation Review (DVVR), this one on Real Time Control and Protection, was completed this week. The external participants included: Tom Todd (EOC chair), Axel Winter (IO), David Humphreys (GA), Michel Huguet (ITER retired), Jim Irby (MIT) and Dave Terry (MIT). The observations/suggestions are now being organized into corrective actions.

A design integration review was completed for the polar region of the machine. Participants included PPPL NSTX-U Responsible Engineers with involved scope, various PPPL subject matter experts, and several Extent of Condition (EoC) committee members including Tom Todd, the EoC Chair. The purpose was to evaluate various design options for the many components involved in this part of the machine. Advantages and disadvantages of various approaches were identified. The results of this review, along with guidance from the final EoC meeting in May, will define the path forward for several major design decisions.

Regarding test cell work, the Poloidal-CHERS diagnostic in-vessel passive plates have completed vacuum preparation (including a bake) following fit-ups, and are ready for installation. The removal, inspection and silver plating of the TF, OH and CHI bus under the machine has started, and the installation and alignment of the FIReTIPS diagnostic wave guides continues.

A Management Safety Walkthrough of the coil winding facility was conducted on April 14. Action items are being addressed.

A Specification and Statement of Work (SOW) for the procurements of Inner PF coils is nearing completion.

Vendor grit blasting of the first spool of PF1A coil conductor began this week.

Work continues in the Neutral Beam Clean Room on the assembly of a second spare ion source. Pre-op testing of the first spare ion source has been successfully completed. Test data has been reviewed, and some steps will be repeated before declaring this source an active spare.

Voith Hydro and PPPL engineers met this week to discuss a possible fixed price subcontract to resurface the D-MG#1 bearing journal in a stoning operation. Also, GE Power Inc. in Pittsburgh will submit a proposal to update the aging MG cyclo-converter controls.

The final design review of the NSTX-U Test Cell Video Surveillance System was held this week.

NSTX-U RESEARCH (J. MENARD):

The paper "Feedback control design for non-inductively sustained scenarios in NSTX-U using TRANSP" by M.D. Boyer, R.G. Andre, D.A. Gates, S.P. Gerhardt, J.E. Menard, and F.M. Poli has been published in Nuclear Fusion. This paper examined a method for real-time control of important plasma performance related parameters during non-inductively sustained scenarios in NSTX-U. The work used TRANSP, a time-dependent integrated modeling code for prediction and interpretive analysis of tokamak experimental data that is developed at PPPL, as a simulator. TRANSP simulations of non-inductively sustained scenarios were used to study the sensitivity of the parameters to disturbances (e.g., changes in confinement characteristics) and the response to the available actuators (independent neutral beam modulation and shaping changes were considered). These results were used to develop a linearized dynamic response model of the system and a multi-variable model-based control scheme was designed that accounts for the tight coupling of magnetic and kinetic variables in non-inductive scenarios, as well as the limited available range of actuation. Simulations show that modest changes in the gap and beam powers can improve response time of the system, reject perturbations, and track target values of the controlled parameters.

The paper "Current Start-Up Using the New CHI System," by K. Kuroda, R. Raman, K, Hanada, et al., was published in Plasma and Fusion Research: Rapid Communications Vol. 12, 1202020 (2017). The paper reports the first results from the recently implemented transient coaxial helicity injection (CHI) system on the QUEST device located at Kyushu University in Japan, including the generation of up to 29 kA of CHI produced toroidal plasma current. The QUEST CHI experiment uses a new CHI electrode configuration, complementary to the ones implemented on NSTX/NSTX-U. The University of Washington and PPPL groups participated in the QUEST CHI experiment as a part of the QUEST/NSTX-U US-Japan collaboration.

The paper titled "Quasilinear diffusion coefficients in a finite Larmor radius expansion for ion cyclotron heated plasmas" by J. Lee (MIT), J. Wright (MIT), N. Bertelli (PPPL), E F. Jaeger (XCEL), E. Valeo (PPPL), R Harvey (CompX), and P. Bonoli (MIT) was published in Physics of Plasmas. In this paper a reduced model of quasilinear velocity diffusion by a small Larmor radius approximation is derived to couple the Maxwell's equations and the Fokker Planck equation self consistently for the ion cyclotron range of frequency (ICRF) waves in a tokamak. The quasilinear diffusion coefficients are implemented in a coupled code (TORIC-CQL3D). In particular, this coupling is done by making use of the recent extension of TORIC, which includes the non-Maxwellian ion effects in the ICRF minority heating regime developed by N. Bertelli and E. Valeo.

J. Menard attended the Chinese Fusion Engineering Test Reactor (CFETR) Physics International Advisory Committee (IAC) Meeting held April 19-20, 2017 in Hefei, China. The IAC was charged to comment on the proposed experimental validation plan, scenario, stability, and exhaust development, and proposed progress metrics.

S. Sabbagh gave a general presentation on plasma, fusion, stability, and PPPL tokamaks to the Austin-Healey Sports & Touring Club on April 18. The group plans to tour PPPL this summer.

ITER & TOKAMAKS (R. NAZIKIAN):

DIII-D:

The article "Recent Upgrades of the DIII-D Impurity Granule Injector" by M. Vorenkamp et al has been accepted for publication in Fusion Science and Technology. The article describes the upgrades of the impurity granule injector (IGI) that enables injection of sub-millimeter granules of materials other than lithium. The upgraded IGI was deployed in DIII-D experiments on ELM pacing with injection of lithium, carbon and boron carbide granules.

A. Nagy gave a presentation on Helicon Project Restart and on DIII-D Facility Needs for installing the MIT Lower Hybrid System on DIII-D.

S. Haskey presented a talk titled "Deuterium charge exchange recombination spectroscopy from the top of the pedestal to the scrape off layer in H-mode plasmas" at the EPS diagnostics conference in France. The talk included details of the edge main ion system on DIII-D, the analysis required to interpret the measurements, and some recent highlights from the system.

THEORY (A. BHATTACHARJEE):

F. Ebrahimi gave a talk on April 17, entitled “Nonlinear reconnecting edge localized modes in tokamaks”,at the NSTX-U Monday Physics Meeting. The abstract reads “Nonlinear dynamics of current-driven Edge Localized Modes (ELMs) is investigated using three-dimensional extended MHD simulations in a toroidal tokamak configuration. To shed light onto the role of reconnection in ELM nonlinear dynamics, we here focus on the effect of finite edge current density. The helicity injection technique is utilized to form plasma current non-inductively. It is shown that in the presence of resistivity, physical current layers developing near the plasma edge can be unstable to 3-D current-sheet instability [1]. We show coherent current-carrying filament (ribbon-like) structures (sometimes referred to as 3-D plasmoids) wrapped around the torus that are nonlinearly formed due to nonaxisymmetric reconnecting current sheet instabilities, the so called peeling-like edge localized modes [2]. These fast-growing modes saturate by breaking axisymmetric current layers isolated near the plasma edge, and go through repetitive relaxation cycles by expelling current radially outward and relaxing it back. The local bidirectional, fluctuation-induced electromotive force (emf) from the edge localized modes, the dynamo action, relaxes the axisymmetric current density and forms current holes near the edge. Our simulations also show the existence of nonaxisymmetric total toroidal current density filament in the edge region (both around the separatix and the open field line regions). The implication of these results for the physics of vertical displacement events (VDEs) during disruption will also be discussed. [1] F. Ebrahimi, Phys. Plasmas 23, 120705 (2016), [2] F. Ebrahimi 2017.

On April 18, M. Churchill (PPPL) presented a Special Theory Seminar on “Transport in the Coupled Pedestal and Scrape-off Layer Region of H-mode plasmas”. Understanding the multi-scale neoclassical and turbulence physics in the edge region (pedestal + scrape-off layer) is

required in order to reliably predict performance in future fusion devices. Churchill presented research exploring characteristics of this transport using the family of X-point Gyrokinetic Codes (XGC). First, the variation of pressure in the scrape-off layer (important to understand in order to avoid divertor wall degradation) is widely believed to follow simple fluid prescriptions, due to high collisionality. However, simulation results in the near-SOL indicate a significant departure from the simple fluid models, even after including additional terms from neutral drag and the Chew-Goldberger-Low form of parallel ion viscosity to the parallel momentum balance. Second, turbulence characteristics in the edge region show nonlocal behavior, including convective transport of turbulent eddies ("blobs") born just inside the closed field line region out into the SOL. These large intermittent structures can be created even in the absence of collisions in the simulation. Tracking these structures show that on average their radial velocity is very small, even in the near-SOL, while their poloidal velocity is significant. The potential structure within these blobs is monopolar with a peak shifted from the density structure, contrary to the dipolar structure expected by analytical models for blob generation and transport based on interchange turbulence. Finally, coherent phase space structures in blobs are searched for, however only broad regions of velocity space are found to show significant structure.

On April 20, T. Stoltzfuss-Dueck (PPPL) presented a Theory Seminar on Parasitic Momentum Flux in the Tokamak Core. Tokamak plasmas rotate spontaneously in the absence of applied torque. This so-called "intrinsic rotation" may be very important for future low-torque devices such as ITER, since rotation can stabilize certain instabilities. In the mid-radius "gradient region," which reaches from the sawtooth inversion radius out to the pedestal top, intrinsic rotation profiles are sometimes flat and sometimes hollow. Profiles may even transition suddenly between these two states, an unexplained phenomenon referred to as rotation reversal. Theoretical efforts to identify the origin of the mid-radius rotation shear have focused primarily on quasilinear models, in which the phase relationships of some selected instability result in a nondiffusive momentum flux ("residual stress"). In contrast to these efforts, the present work demonstrates the existence of a robust, fully nonlinear symmetry-breaking momentum flux that follows from the free-energy flow in phase space and does not depend on any assumed linear eigenmode structure. The physical origin is an often-neglected portion of the radial ExB drift, which is shown to drive a symmetry-breaking outward flux of co-current momentum whenever free energy is transferred from the electrostatic potential to ion parallel flows [1]. The resulting rotation peaking is counter-current and scales as temperature over plasma current. As originally demonstrated by Landau [2], this free-energy transfer (thus also the corresponding residual stress) becomes inactive when frequencies are much higher than the ion transit frequency, which may explain the observed relation of density and counter-current rotation peaking in the core. Simple estimates suggest that this mechanism may be consistent with experimental observations, in both hollow and flat rotation regimes. [1] T. Stoltzfus-Dueck, Phys. Plasmas 24, 030702 (2017). [2] L. Landau, J. Phys. (U.S.S.R.) 10, 25 (1946).

D. Pfefferlé and E. Hirvijoki (PPPL) have published a paper, Phys. Plasmas 24, 042118 (2017), titled "Exact collisional moments for plasma fluid theories", appearing in Physics of Plasmas. The velocity-space moments of the often troublesome nonlinear Landau collision operator are expressed exactly in terms of multi-index Hermite-polynomial moments of distribution functions. The collisional moments are shown to be generated by derivatives of two well-known functions, namely, the Rosenbluth-MacDonald-Judd-Trubnikov potentials for a Gaussian distribution. The resulting formula has a nonlinear dependency on the relative mean flow of the colliding species normalised to the root-mean-square of the corresponding thermal velocities and

a bilinear dependency on densities and higher-order velocity moments of the distribution functions, with no restriction on temperature, flow, or mass ratio of the species. The result can be applied to both the classic transport theory of plasmas that relies on the Chapman-Enskog method, as well as to derive collisional fluid equations that follow Grad's moment approach. As an illustrative example, we provide the collisional ten-moment equations with exact conservation laws for momentum- and energy-transfer rates.

ENGINEERING & INFRASTRUCTURE (V. RICCARDO):

Fabrication and Operations Division (E. Perry, L. Dudek, Y. Zhai):

The Judgement of Needs (JON's) report for the tritium in the NSTX-U VV event has been signed off by the investigative committee. Corrective actions resulting from the incident have begun.

Preparations continue for the Tritium Stabilization / Removal FDR. The review is scheduled for April 27.

The annual security inspection of the Tritium Area was conducted by Site Protection. The Tritium Area has been found to be in compliance with applicable DOE guidance.

Calibrations of the machine tools in RESA building commenced this week. They will continue next week.

Corrective actions for the safety items identified last Friday during the walk-thru in the CS Highbay have been implemented except for the Fire Engineer approval of canopies over the coil winding equipment. Engineering is working with the PPPL Fire Engineer to develop approved solutions to protect the coil winding area from contamination.

The s/c coil current ramp testing wasn't successful as planned. The coil quenched at 250 A and the test was stopped.

ENVIRONMENT, SAFETY, & HEALTH (J. LEVINE):

PPPL celebrated Earth Week with a number of activities for employees. Twenty-five volunteers spent the morning of April 18 picking up trash and recyclables around the campus. The volunteers collected nearly 400 pounds of debris, including 117 pound of trash and 280 pounds of recyclable materials. Over 1,800 pounds of personal electronics were collected for recycling at UNICOR. On April 19, PPPL gathered to recognize the commitment to sustainability of employees and employee teams with the annual Green Machine Awards, followed by a screening of the film Anthropocene. In the afternoon Dr. Alan Robock, Distinguished Professor of Environmental Sciences at Rutgers University presented a colloquium talk on the effects of nuclear war on climate and agriculture.

R. Sheneman and J. Wohlberg attended the annual training workshop and business meeting of the DOE Export Control Coordinators Organization (DOE-ECCO) in Washington, DC on April

18-20. The workshop included regulatory/enforcement updates from the Departments of Energy, State, Commerce, Homeland Security and Treasury and the Nuclear Regulatory Commission. Representatives from DOE labs and sites also shared lessons learned and best practices in the areas of export compliance, non-proliferation and national security.

Material Services handled 16,400 pounds of scrap metal from all Lab areas, and 30,440 pounds of wire from the S1/S2 cable project was recycled on April 13.

STOP Training was provided for five employees on April 19.

OFFICE OF ACADEMIC AFFAIRS (N. FISCH):

Jonathan Marc Jara-Almonte successfully earned his PhD on April 24 by presenting his thesis project, titled, "Multiple-Scale Physics During Magnetic Reconnection ". His committee members were S. Prager (Chair), R. Majeski, and W. Tang. His adviser was H. Ji.

DIRECTOR'S OFFICE (S. ZELICK):

Site Protection (F. White):

Ambulance 166 responded to Plainsboro for one mutual aid assignment.

Ambulance 166 responded to Princeton for one mutual aid assignment.

Engine 66 responded to Princeton for six mutual aid assignments.

Engine 66 responded to Plainsboro for one mutual aid assignment.

Members of Site Protection Division conducted an Emergency Management Review Committee (EMRC) meeting.

Members of Site Protection Division commenced "Nozzles and Hoses" training.

Members of Site Protection Division participated in a DOE "Eagle Horizon 2017" preparatory conference call.

Technology Transfer & Publications (L. Bagley):

Two investor groups are being courted for the licensing of the Miniature Integrated Nuclear Detection System (MINDS) technology. Export control classifications and an LDRD proposal for additional Research and Development are underway. An SPP is under review with a consumer products company to develop a plasma-based consumer or professional product. LDRD research is underway with a proton therapy center to improve their diagnostic procedure with PPPL's spectroscopy expertise.

Princeton Satellite Systems (PSS), the licensee of PPPL's Princeton Field Reversed Configuration (PFRC) fusion engine technology, was awarded a Phase II NASA Innovative Advanced Concepts (NIAC) grant for "Fusion-Enabled Pluto Orbiter and Lander", as well as two NASA STTRs for "High Efficiency RF Heating for Small Nuclear Fusion Rocket Engines" and "Superconducting Coils for Small Nuclear Fusion Rocket Engines." All three projects will result in funding via PSS for additional research on PFRC at PPPL.

PPPL's overall submission rate for publications to DOE's Office of Scientific and Technical Information (OSTI) is 49%. The submission rate for papers where a PPPL author is the first author is 85% and the non-PPPL first author submission rate is 28%.

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