Weekly HIGHLIGHTS

PPPL PRINCETON PLASMA PHYSICS LABORATORY

U.S. DEPARTMENT OF ENERGY

The PPPL Highlights for the week ending March 24, 2017 are as follows:

U.S. ITER FABRICATION (H. NEILSON):

ITER Steady State Electrical Network (J. Dellas):

LV Distribution and Sub-distribution Panels: Arrangement has been signed which transfers to IO-CT the responsibility to procure, on behalf of US ITER, along with UPS and DC Distribution batteries. Full payment for the arrangement has been made to the ITER Organization. A single credit request of 2.16 KIUA for IP LV Distribution will be made upon delivery of the UPS and DC Distribution equipment.

ITER Diagnostics (R. Feder):

Upper Wide Angle View VIS-IR Cameras (UWAVS): The Visible and InfraRed Back End Optical Chamber camera and filter design continues. The Instrumentation and control effort has also begun. Several meetings occurred to define the scope of work for each participant: GA, PPPL and Bertin. Mirror cleaning R&D is complete and the report is being drafted.

Upper Port Plugs 11 & 14: UP14 Port Integrator (PI) team had a meeting with Design Integration (DI) team from the IO. PI suggested bringing Cable trays inside the Interspace support structure (ISS) to make the connection to the Electrical Feedthrough. DI agreed it is possible and will look into as it solves this generic issue. Various other service routing through the ISS were discussed. UP14 team is revising the DSM support frame that will be made from 316LN-IG plate. In current design this frame is made from Square tubes. It was realized that these tubes may not be available in 316LN-IG material, and would have to be custom ordered. To avoid additional cost for customizing, UP14 team is looking into making it from plates. Document Deliverable CheckList (DDCL), that lists all the documents, from design requirements to design justification and evaluation, is filed in iDocs. This list is needed the conducting PDR/FDR for each diagnostic system and port plugs.

Equatorial Port 09: Electrical feedthrough design options were reviewed and a design by the EUDA is a favorite for EP09. Much of the design effort would be undertaken by the EU, relieving USDA of development cost and effort. Feedthrough considerations are also prompting Port Integration to study maintenance and Remote Handling questions for in-vessel components in the very near future.

Core Imaging X-Ray Spectroscopy (CIXS):A deviation request to remove the difficult port internal view of the CIXS diagnostic is in the works. This week Dave Johnson finished up the

viability report for the internal view. With the preliminary information collected, the deviation request is moving forward.

Motional Stark Effect (MSE): The US/IO monthly meeting was held this week with significant discussion on the MSE PDR and the path forward to completing both MSE in EP01 and EP03. The idea is now to split the MSE PDR into multiple smaller PDR's that cover EP01 and EP03 individually. This will allow us to focus on EP01 which is a EU port, while EP03 can be delayed dependent on our schedule since EP03 is a US port. Significant problems for the MSE come from the shutter design and calibration design. Currently there is a placeholder in the line diagrams for a calibration wheel, which would be near impossible to implement. There was discussion on switching out the calibration wheel to a single polarizer and have that rotate in place.

ITER Analysis Team: High neutron flux as a result of neutron streaming along the VisIR piping inside U14 Port plug has been reviewed. Potential solution to mitigate closure plate activation issue and shutdown dose rate concentration in interspace region has been discussed.

NSTX-U RECOVERY PROJECT (R. HAWRYLUK):

The Design Verification and Validation Review (DVVR's) of the NSTX-U Vacuum and Fueling systems was held this week, and observation/suggestions (chits) are now being organized into corrective actions. This was the ninth of twelve reviews. The external reviewers included Paul LaMarche (PU), Hatt Hansink (GA), Rui Viera (MIT), and Jim Irby (MIT).

A charge letter, preliminary agenda and Systems Design Description for the NSTX-U Bakeout System DVVR, scheduled for March 30, was distributed to the review team.

The assembled neutral beam ion source slated to be our first spare has successfully completed hydrostatic testing, and is expected to be ready for electrical insulation testing next week.

Regarding test cell work, initial machining of the Poloidal-CHERS diagnostic in-vessel passive plates has been completed, and fit-ups are in progress in preparation for completing modifications to the mounting structures. Installation and alignment of waveguides for the FIReTIPS diagnostic continues, and the removal of the Deposition Monitor and Dust Collector from the NSTX-U vessel has started. The bay H mid-plane port cover has been removed from the vessel to provide access for repair of a known leak on the neutral beam armor plates.

The lower guide bearing shoes of motor generator (MG#1) have been removed to allow for a full inspection of the shaft journal.

NSTX-U RESEARCH (J. MENARD):

S. Kaye attended the Exascale Crosscutting Review held in Tyson's Corner, VA on March 9-10. The purpose of this review was to identify and prioritize High Performance Computing (HPC) issues that cut across Office of Science programs to allow for deeper collaborations and more

efficient software/hardware development among HPC/SciDAC efforts across the Office of Science.

F.Poli visited the University of York on March 13 and 14. She gave a seminar entitled, "The role of integrated modeling in discharge analysis, prediction, and for development of more robust control algorithms." The seminar covered the work funded under the ITER Task Agreement on electron cyclotron analysis and also provided a short summary of the work performed for lower-hybrid current drive analysis on C-Mod and for the non-inductive startup on NSTX-U. Poli also held discussions with E. Du Toit and R. Vann related to using a 0D code developed by Du Toit for the simulation of electron Bernstein wave (EBW) startup on NSTX-U. The code, which has Fokker Planck calculations that are 0D in space, but 2D in velocity space, can reproduce EBW startup experiments on MAST, and includes the current build-up and the evolution of the magnetic flux surfaces from open to closed.

S. Sabbagh and S. Kaye attended the second of two ITER Research Plan Workshops on March 14-17 as United States representatives on the review committee. The aim of the workshop was to begin the writing process of the new ITER Research Plan document within the staged approach, leading from first plasma through full DT operation and towards long pulse/steady-state fusion power production. Sabbagh participated in the Working Group on the commissioning of the plasma control system through all operational phases and including MHD control and disruption mitigation. Kaye participated in the Working Group developing the research plan for the long-pulse, steady-state program, which will be carried out after the Q=10 demonstration, with preparatory research beginning in the non-nuclear campaigns.

On March 16, J. Menard gave a seminar presentation at the Los Alamos National Laboratory (LANL) entitled “Motivations for advanced divertor system and materials research in next-step fusion facilities and NSTX Upgrade”. Menard also toured several LANL research facilities including the Plasma Liner Experiment and the Ion Beam Materials Laboratory and discussed possible NSTX-U-related collaboration opportunities with LANL researchers.

NSTX-U collaborators from the University of Wisconsin-Madison have initiated collaboration with the MAST-U facility on particle transport, fueling and exhaust. This initiative in the group of Professor O. Schmitz establishes a direct comparative research environment to study Resonant Magnetic Perturbation (RMP) effects on advanced divertors between NSTX-U and MAST-U. Two PhD students from UW Madison visited the MAST-U research team several times in the last six months, which enabled them to make an experimental proposal for the upcoming MAST-U campaign.

An NSTX-U Team Meeting was held on March 22. Agenda items included discussions of Safety Issues by J. Levine, Highlights from DVVRs and an Overview of Extent of Condition Review and Recovery Actions by S. Gerhardt and R. Hawryluk, and Research Program status and plans by J. Menard.

An NSTX-U Plasma Facing Components Requirements Working Group (PFCR-WG) has been formed to assist the Recovery Project and longer-term operational goals of NSTX-U. The group will be led by Matt Reinke (ORNL) with Mike Mardenfeld serving as deputy.

R. Goldston attended the IAEA Technical Meeting on Steady-State Operation of Magnetic Fusion Devices. He made a presentation titled, "New Scaling for Plasma Detachment and its Implications for Power Plant Design." Working with Matt Reinke and Jacob Schwartz, he found (and has published in PPCF) that the impurity concentration required for plasma detachment scales as Psep/Bp, in strong contrast with the usual assumption that divertor operation is best characterized by Psep/R or Psep*B/R. This implies that tokamak reactor designs, which are generally driven by power handling considerations, should move to higher fields rather than to larger size. He also reported that the same analysis indicates that lithium can be used as an effective divertor radiator, and should be able to achieve higher divertor plasma enrichment compared with the main plasma than higher-Z impurities.

The following NSTX-U related papers were published in the special issue of Fusion Engineering and Design for the fourth International Symposium on Liquid Metal Application for Fusion Device (ISLA-4) which was held on September 28 - 30, 2015 at Granada, Spain: "Liquid lithium applications for solving challenging fusion reactor issues and NSTX-U contributions," by Masayuki Ono (PPPL) et al., Fusion Eng. Des. 117 (2017) 124; "Hydrogen retention in lithium on metallic walls from in vacuo analysis in LTX and implications for high-Z plasma-facing components in NSTX-U," by Robert Kaita (PPPL), Fusion Eng. Des. 117 (2017) 135; "Hydrogen and helium recycling from a JxB-force convected liquid metal Ga67In20.5Sn12.5 under steady state plasma bombardment," by Yoshi Hirooka (NIFS, Japan) et al., Fusion Eng. Des. 117 (2017) 140; and "Effect of progressively increasing lithium conditioning on edge transport and stability in high triangularity NSTX H-modes" by Rajesh Maingi (PPPL). Also presented but published prior to the special issue was "Lithium granule ablation and penetration during ELM pacing experiments at DIII-D," by R. Lunsford (PPPL) et al., Fusion Eng. Des. 112 (2016) 621; and "Upgrades toward high-heat flux, liquid lithium plasma-facing components in the NSTX-U," by M. Jaworski (PPPL), et al., Fusion Eng. Des. 112 (2016) 93.

Lucas Morton of Oak Ridge Associated Universities (ORAU) visited DIII-D for two week. Lucas is a postdoc based by General Atomics at PPPL to work on resistive stability on NSTX-U (in comparison to NSTX and DIII-D). He worked with Rob La Haye on NSTX-U analysis and took part in the DIII-D experiment on "Influence of Local Electron Cyclotron Power on Tearing Stability in the Low-Torque ITER Baseline Scenario in DIII-D".

C. Myers, S. Sabbagh, and J. Park each made remote presentations at the ITPA Meeting on MHD, Disruptions, and Control, held at the Southwestern Institute of Physics in Chengdu, China. The talk "Report on working group WG-6 Non-Axisymmetric currents during VDEs" by Myers illustrated the status of a multi-machine halo current study examining the scaling of halo current rotation during plasma disruption. The talk "Report on joint experiment MDC-21 Global mode stabilization physics and control" by Sabbagh highlighted the recently-published, first predictive results of a reduced model of global mode stability as processed by the Disruption Event Characterization and Forecasting (DECAF) code, and new RWM active control results in DIII-D. The talk "Investigation of the Generalized Neoclassical Toroidal Viscosity Offset Rotation Profile and implications for ITER" by Sabbagh summarized recent results from the KSTAR superconducting tokamak that have generated toroidal plasma rotation in the co-Ip direction and large rotation profile shear by using 3D fields, with comparisons to ITER simulations. The talk "Report on joint experiment MDC-19 Error Field Control at Low Plasma Rotation" by Park summarized the status of the review report on error field correction criteria for

ITER as requested, and also the new research progress on error field physics in multiple devices including NSTX-U, COMPASS, KSTAR and EAST.

ITER & TOKAMAKS (R. NAZIKIAN):

EAST: R. Maingi attended the EAST General Planning Meeting and presented a talk, "Proposals from the US-China PMI Collaboration." Experiments were proposed in the areas of optimization of lithium delivery techniques for ELM control, RMP ELM control, and RF collaborations. In addition data analysis and paper preparation from experiments in December 2016 was continued. Finally a conference call between the US and ASIPP team on IR thermography and MAPES capabilities was held.

KSTAR: The long awaited shipment of the C-MOD MSE polychromators to KSTAR took place this week. Delivery is scheduled on or before March 31. This completes the set of MSE background polychromator equipment that we will ship to NFRI this year. The background polychromator will be assembled in April. It will be used for improving MSE measurements during the KSTAR spring/summer experimental campaign. An assessment of the utility of the background measurement will be made this fiscal year.

ADVANCED PROJECTS (H. NEILSON):

Stellarators (D. Gates):

PPPL engineer D. Loesser reported progress in assembly trials for the Wendelstein 7-X (W7-X) divertor scraper. Loesser, together with PPPL technician R. Miller, are visiting the W7-X project site in Greifswald, Germany, to participate in these operations. A trial assembly of the scraper base plate into the W7-X vacuum vessel mockup was completed without difficulty, validating the interface between the PPPL-fabricated scraper unit and the W7-X machine. In the next step, the unit was taken into the actual W7-X vacuum vessel and placed in position, confirming the validity of the planned access path and the interface with the as-built machine. Since actual installation of the scraper is planned to occur during a vessel opening in the middle of the upcoming OP1.2 operating campaign, it is critical to minimize risks of delay due to unforeseen installation problems. As a result of these successful assembly trials, that risk is substantially mitigated.

S. Lazerson visited IPP-HGW this week in fulfillment of his role as the Scenario and Integration Task Force Leader for OP1.2a on W7-X. While there he participated in discussions regarding the OP1.2a workshop. In addition, he met with researchers in regards to measurement of the superconducting coil set, calibration of magnetic diagnostics, development of between shot equilibrium reconstruction capabilities, and collaboration on energetic particle modeling activities for the OP1.2b experimental campaign. He will present the overview of the OP1.2a Scenario and Integration Task Force next week at the workshop.

N. Pablant completed a month long stay at the National Institute for Fusion Science (NIFS) in Japan. This trip was part of the NINS (National Institutes of Natural Sciences) / NIFS Strategic International Research Interaction Acceleration Initiative. During this trip Novimir was able to

participate in the first deuterium campaign on LHD, including attendance of the first deuterium plasma ceremony. The research projects undertaken included the development of library to allow the generation of a VMEC equilibria for any given LHD shot and time based on the LHD equilibrium database. This library provides an interpolated VMEC equilibria that is fully consistent with real-space to flux-space mapping files typically generated at LHD. The ability to generate VMEC equilibria now allows many standard stellarator/heliotron codes to be run for LHD in a manner consistent with the existing LHD analysis and diagnostic mapping. This VMEC library was then integrated into the XICS stellarator analysis suite providing for the first time a system that can provide automatic analysis of inverted XICS profiles on LHD. This automatic analysis library for the LHD XICS system is now complete and analysis of all data from the XICS system on LHD has now begun. This capability for automatic analysis will allow the XICS system to be fully utilized by all researchers and collaborators on LHD.

System Studies (C. Kessel):

C. Kessel, R. Majeski, and A. Khodak from PPPL travelled to NIFS for the JA/US Workshop on Fusion Power Plants/Next Steps and Fusion Technologies. In addition, J. Blanchard from University of Wisconsin and M. Tillack from UCSD from the FESS team attended as well. Kessel presented an overview of the FNSF project and the goals of the recently started liquid metal PFC study, the core and edge physics assessment and systems analysis for the FNSF. Majeski presented a conceptual design for a liquid metal first wall and divertor, and benefits and challenges of liquid metal PFCs. Khodak presented liquid metal PFC thermo-mechanics analysis, and detailed thermo-mechanics of a solid breeder blanket with accident modeling. Progress on the Helical fusion reactor, and Japanese DEMO tokamak reactors was reported. Detailed examinations were reported in design window identification, JA DEMO program and commissioning studies, divertor design activities, simple 1D SOL/divertor models, vapor shielding under transient loads, liquid metal experiments, stellarator divertor heating assessments and designs, maintenance, neutronics, and core and edge plasma physics. This is a continuing workshop started in the early 1990's with the ARIES studies, and these presentations will be posted on the FESS website.

THEORY (A. BHATTACHARJEE):

On March 23, Professor Yasuhiro Suzuki (National Institute for Fusion Sciences, Japan) presented a theory seminar on recent progress of understanding 3D magnetic topology in stellarators and tokamaks. The 3D equilibrium calculation is a fundamental consideration to understand the magnetic topology. In particular, for stellarators, the topological change due to the beta-sequences has been found and it is an important issue how to make good flux surfaces in general 3D configuration in the presence of the plasma beta. On the other hand, the 3D equilibrium calculation is also an important issue for tokamaks, because the RMP is widely used to control the stability and transport. In this talk, recent results of 3D equilibrium calculations based on the HINT code, which is a 3D equilibrium calculation code without an assumption of perfectly nested flux surfaces. Impacts of the beta-sequences and the plasma rotation will be discussed.

A paper simulating sheath physics with the continuum kinetic version of Gkeyll has appeared in Physics of Plasmas [P. Cagas, A. Hakim *et al.*, Phys. Plasmas 24, 022118 (2017); doi:]. The code

uses a novel version of the finite-element discontinuous Galerkin scheme that conserves energy in the continuous-time limit. The fields are computed using Maxwell equations. Ionization and scattering collisions are included; however, surface effects are neglected. Kinetic results are compared with those obtained from an already established finite-volume multi-fluid model also implemented in Gkeyll. The work presented here demonstrates that the kinetic and fluid results are in agreement for the momentum flux, showing that in certain regimes, a multi-fluid model can be a useful approximation for simulating the plasma boundary. Besides decompression cooling, the heat flux is shown to play a role in the temperature differences that are observed, especially inside the collisionless sheath.

I. Dodin (PPPL), Andrey Zhmoginov (Berkeley, now at Google), and D. Ruiz (PPPL) published a paper titled "Variational principles for dissipative (sub)systems, with applications to the theory of linear dispersion and geometrical optics" [Phys. Lett. A 381, 1411 (2017)]. The paper proposes a variational principle that captures collisionless dissipation without invoking ad hoc techniques such as doubling of variables. It is shown that, for a broad class of dissipative systems of practical interest, variational principles can be formulated using constant Lagrange multipliers and Lagrangians nonlocal in time, which allow treating reversible and irreversible dynamics on the same footing. A general variational theory of linear dispersion is formulated as an example. In particular, a variational formulation is presented for linear geometrical optics in a general dissipative medium, which is allowed to be nonstationary, inhomogeneous, anisotropic, and exhibit both temporal and spatial dispersion simultaneously.

This report is also available on the following web site:
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