American Nuclear Society
Fusion Energy Division
December 2017 Newsletter

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Letter from the FED Chair, Arnold Lumsdaine, Oak Ridge National Laboratory, Oak Ridge, TN.

The most important news for the Fusion Energy Division (FED) this year will be detailed in other parts of this newsletter, but I will highlight some of these significant activities in the December 2017 version of the "Letter from the FED Chair".

The ANS journal, *Fusion Science and Technology (FS&T)*, has a new editor designate after a year-long search process. Congratulations to Leigh Winfrey, Associate Professor at the University of Florida, (and FED Executive Committee member), on her appointment! In the last newsletter, we expressed our thanks for Nermin Uckan for her leadership as editor for the last 17 years, but it cannot be stated enough – the journal is in the strong position that it is today because of Dr. Uckan's tireless and persistent leadership, and we all owe her our appreciation and thanks. *Fusion Science and Technology* is unique among the ANS journals in being closely tied to a single ANS division – the Fusion Energy Division. I am confident that Dr. Winfrey's vision and energy will lead the journal effectively into a new era. It is incumbent upon us to support her in whatever way we can to ensure the continued success and growth of FS&T.

The 2017 Winter ANS meeting took place from October 29-November 2 in Washington, DC, and included three sessions sponsored or co-sponsored by the Fusion Energy Division. A highlight was a panel session on "Research Opportunities in Advanced Fission and Fusion Materials" which was chaired by Brian Wirth (University of Tennessee, Knoxville) and included the following distinguished panelists:

- Rory Kennedy (INL) – Perspectives from NSUF
- Rita Baranwal (INL) – Perspectives from GAIN
- Bill Corwin (DOE-NE) – Materials needs for advanced fission reactors
- Daniel Clark (DOE-FES) – Materials developments for fusion
- Lance Snead (MIT, Stony Brook University) – Silicon carbide
- Steve Zinkle (University of Tennessee, Knoxville) – Nano structured alloys

The presentations and the interactions that followed were remarkable. The discussion not only informed the attendees, but will hopefully have longer impacts in building new bridges, and perhaps moving our communities towards solving some seemingly insoluble problems in the development of advanced materials for extreme environments.

We continue outreach activities to students and young members in order to keep the society and the division strong for the future. On October 3, I gave a presentation on the Fusion Energy Division in a webinar that was arranged by Matt Jasica of the Young Members Group. This will soon be available on the YMG web site (http://ymg.ans.org/) for any who are interested. The FED Executive Committee has decided (for the first time) to give a small award ($250) for the best paper submitted to FED at the ANS Student Conference, which will be at the University of Florida from April 5-7, 2018 (http://ansstudentconference2018.com/). We will also give this student another $250 towards presenting their work at an ANS national meeting. This is in addition to the support that we regularly give towards student meetings. Please spread the word. Additionally, we had three FED executive committee members (Keith Rule, Leigh

Winfrey, and I) attend the ANS Young Professional's Congress outreach luncheon. The Congress took place on October 28 – the day before the start of the ANS Winter Meeting – and included a strong technical program, as well as mentoring opportunities such as the outreach luncheon.

Finally, the biggest event that the division sponsors is our biennial topical meeting on the Technology of Fusion Energy (TOFE). It is now less than a year away. The 2018 TOFE will be embedded with the ANS Winter meeting in Orlando, Florida from November 11-15. The details of the technical program are developing, and I expect a strong, interesting, and impactful set of presentations and posters. And while the distinguished plenary and invited speakers are critical to the technical program, the success of the meeting really depends on broad participation by FED members, and the larger international fusion engineering and technology community. Please plan to participate, and spread the word among your colleagues and associates.

On behalf of the Executive Committee of the Fusion Energy Division, I wish you all a happy holiday season.

New ANS "Fusion" Fellows – December 2017, Nermin A. Uckan, FED Honors & Awards Chair, Oak Ridge National Laboratory, Oak Ridge, TN.

The election to the rank of Fellow within the ANS recognizes the contributions that individuals have made to the advancement of nuclear science and technology through the years. Selection comes as a result of nomination by peers, careful review by the Honors and Awards Committee, and election by the Society's Board of Directors. The list of current fellows, nomination steps, guidelines, and nomination forms can be found at http://www.ans.org/honors/va-fellow.

It is a pleasure to report that we have two new ANS "Fusion" Fellows added to the honors rank: **Prof. Ronald M. Gilgenbach** (University of Michigan, Ann Arbor, MI) and **Prof. Brian D. Wirth** (University of Tennessee, Knoxville/Oak Ridge National Laboratory, Oak Ridge, TN). Congratulations for both for the well-deserved honors.

Ronald M. Gilgenbach is honored "for pioneering research on the science and technology of fusion devices and accelerators, including the first electron cyclotron heating and pre-ionization of tokamak plasma in the USA, innovative high power mm-wave/microwave source development, high-energy density z-pinch plasma generators, plasma and electron beam instability characterization and mitigation."

Brian Wirth is recognized "for seminal contributions to fundamental understanding of radiation damage in nuclear reactor materials providing the scientific basis for improved predictions of reactor performance and development of more damage tolerant materials of advanced fission and fusion power systems."

FED has two-dozen or so active Fellows. During the past couple of years, FED members have been working diligently to add one-to-two well-deserving colleagues a year to the FED Fellows roster. We need to continue this positive trend and keep nominating our colleagues. Please remember that one cannot get recognized and elevated to the Fellow status (or receive any award of any kind), unless nominated. Susana Reyes (sreyes@lbl.gov) will be your new FED Honor's and Awards Chair, starting in 2018.

Slate of Candidates for 2018 FED Election, Susana Reyes, Lawrence Berkeley National Laboratory.

As typically happens in even years, the current FED Ex-Co officers will be completing their 2-year terms in June 2018, as will the following three members of the Executive Committee: Chase Taylor (INL), Ahmad Ibrahim (ORNL), and Takeo Muroga (NIFS). I take this chance to thank them all for their contributions on behalf of the Division.

We have an excellent set of fusion researchers running for the officer positions, as well as the three executive committee seats in this election. Their willingness to contribute their time and talents to the division is appreciated by the FED. Our list of candidates for the coming election, which was approved by the current Executive Committee at its recent meeting on October 31, 2017, is:

Vice Chair/Chair-elect:

- Paul Wilson (Univ. Wisconsin)
- Leigh Winfrey (Univ. Florida)

Secretary/Treasurer:

- Lauren Garrison (ORNL)

Ex-Co seats:

- Jan Berry (US-ITER)
- Brian Wirth (Univ. Tennessee)
- Takumi Hayashi (QST, Japan)
- Gregg Morgan (SRNL).

As a next step, you should expect an E-mail announcement from ANS about E-ballots to all members of the FED sometime at the beginning of 2018. The FED Nominating Committee is always looking for fusion professionals, who are willing to serve the division. If you are interested in becoming active in the division governance, please contact any member of the Executive Committee.

2018 ANS-FED Awards – Call for Nominations, Susana Reyes, Lawrence Berkeley National Laboratory.

The Honors and Awards Committee of Fusion Energy Division of American Nuclear Society (ANS-FED) is seeking nominations for two ANS-FED Awards:

- Outstanding Achievement Award: This award is for recognition of a continued history of exemplary individual achievement requiring professional excellence and leadership of a high caliber in the fusion science, and engineering area.
- Technical Accomplishment Award: This award is for recognition of a specific exemplary individual technical accomplishment requiring professional excellence and leadership of a high caliber in the fusion science and engineering area.

Detailed descriptions of the awards (purpose, criteria, and procedure) and past recipients can be found at http://fed.ans.org/awards

Note that the nominees will only be considered for the particular award for which they are nominated. **The nomination deadline is June 1, 2018**. The awards will be presented at the 23rd ANS Topical Meeting on the Technology of Fusion Energy (23rd TOFE), which will be embedded in the ANS annual meeting in Orlando, FL, November 11-15, 2018.

Nomination package must include:

1. The nomination letter including a description of the exemplary achievements and the recommended citation to appear on the award plaque.
2. Additional letters supporting the nomination (a minimum of three and a maximum of five, including the nominator letter).
3. Nominee's CV and publication list.

Incomplete submissions will not be considered. Please send complete nomination packages electronically to:

Susana Reyes
ANS-FED Honors & Awards Chair
sreyes@lbl.gov

Nominators of 2016 nominees are encouraged to update their nomination packages and re-submit electronically.

An Outstanding Student paper award will also be given at the 23rd TOFE meeting through a separate process. Details of the Outstanding Student paper award will be forthcoming in conjunction with the meeting announcement.

Fusion Award Recipients, Laila El-Guebaly, Fusion Technology Institute, University of Wisconsin-Madison, Madison, WI.

Fusion awards have been established to formally recognize outstanding contributions to fusion development made by members of the fusion community. The following awards (listed in alphabetical order) were available to the newsletter editor at the time of publishing this newsletter. We encourage all members of the fusion community to submit information on future honorees to the editor (laila.elguebaly@wisc.edu) to be included in future issues. The ANS-FED officers and executive committee members congratulate the honored recipients of the 2017 fusion awards on this well-deserved recognition and our kudos to all of them.

Edward Teller Medal

The recipients of the 2017 Edward Teller Medal are:

- **R. Paul Drake** is awarded the Edward Teller Medal for seminal work in radiation hydrodynamics, hydrodynamics, and laser-plasma interactions, and for educational contributions, advancing fundamental high-energy-density physics and its applications to astrophysics.
- **Vladimir Tikhonchuk** is awarded the Edward Teller Medal in recognition of his outstanding contributions to understanding of laser-plasma coupling and the original design of alternative schemes of fast ignition, both in theory and experiments.

FPA Awards

The Fusion Power Associates (FPA) Board of Directors has selected the recipients of its 2017 Distinguished Career, Leadership, and Excellence in Fusion Engineering Awards. All awards including a Special Award have been presented this year at the FPA 38th Annual Meeting and Symposium, December 6-7, 2017 in Washington, DC.

2017 Distinguished Career Awards presented to:

- **Steve Cowley** (UKAEA) is recognized for "his many years of dedication to advancing the prospects for fusion power" and especially "for decades of outstanding career contributions as a scientist and his role as an effective spokesperson bringing the fusion message to other scientists, to lay audiences and to politicians worldwide"
- **Farrokh Najmabadi** (UCSD) is recognized for "his many years of dedication to advancing the prospects for fusion power" and especially "for decades of outstanding career contributions as a scientist and leader of fusion power plant studies that have provided perspective on the requirements for future commercial fusion electrical power plants"
- **Stewart Prager** (Princeton University) is recognized for "his many years of dedication to advancing the prospects for fusion power" and especially "for decades of outstanding career contributions as a scientist, educator, manager, and advisor on all aspects of plasma physics, fusion energy and fusion policy"
- **Bob McCrory** (Univ. of U. Rochester) is recognized for "the scientific contributions and leadership he has provided over many decades to the fields of inertial confinement fusion, high power lasers, direct-drive concepts and high

energy density plasma science, as well as to the development of the U. Rochester Laboratory for Laser Energetics as a world-class scientific institution."

2017 Leadership Awards presented to:

- **Bernard Bigot** (ITER Organization) is recognized for "the leadership he has providing to ITER, the most challenging project in the history of the world fusion effort" and especially for "the management and political skills he is bringing to this historic international venture"
- **Valeri Goncharov** and **Craig Sangster** (U. Rochester) are recognized (jointly) for "the leadership they are providing for direct-drive inertial fusion, including their pioneering work on the hydro-equivalent implosion campaign on OMEGA" and especially for "the leadership they have been providing to efforts to ensure a close collaboration between experiments and design/theory".

2017 Excellence in Fusion Engineering Awards presented to:

- **Chris Holcomb** (LLNL, assigned to General Atomics) is recognized for "his scientific contributions to a range of topics, including diagnostics for plasma current profile measurements and external heating options for controlling tokamak current profiles; and the leadership he is providing to national and international efforts directed toward developing the physics basis for achieving steady-state tokamak operations"
- **Adam Sefkow** (U. Rochester) is recognized for "his many scientific contributions on a range of topics, including magneto-inertial fusion, short-pulse and long-pulse laser-plasma interaction physics, and intense charged-particle beam transport; and the leadership he is providing toward establishing predictive capability through collaborations with experiments at all three of the nation's flagship high-energy-density facilities."

2017 Special Award presented to **Dale M. Meade** (PPPL). In selecting Dale, the FPA Board "recognizes and expresses its appreciation to Dale on behalf of the fusion community for the many special services he has been providing, including the establishment and continuation of the popular FIRE website, that both archives important historical fusion documents and keeps the world fusion community abreast of current developments. The Board also recognizes and expresses its appreciation to Dale for his support of FPA, including collecting and archiving the presentations from the FPA annual meetings and for serving on the FPA Board of Directors."

Miya-Abdou Award

The 13th International Symposium on Fusion Technologies awarded the Miya-Abdou Award for Outstanding Technical Contributions to the Field of Nuclear Technology (FNT) for scientists below 40 years old:

- **Jing Song** from the Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences, for her outstanding contributions to the development of fusion neutronics methods and codes
- **Hiroo Kondo** from the National Institute for Quantum and Radiological Science and Technology, Japan for his outstanding contributions to the development of fusion relevant liquid metals technologies.

Larry Foreman Award

As is traditional for the Target Fabrication Specialists Meeting, the Larry Foreman Award was presented to an individual who has made a substantive contribution toward innovation and excellence in target fabrication. The award was presented this year to the retired LLNL employee Dr. **Robert Cook** for his body of work in capsule and coating developments for ICF targets. Bob made essential contributions to the microencapsulation process for making polystyrene and PAMS shells, and to the vapor deposition processes for GDP and beryllium shells. Further, he has been a motivating mentor for future scientists in this community, and year-after-year, he has been a guest editor for the TFM meeting proceedings published by FS&T even in retirement.

Nuclear Fusion Award

The winner of the 2017 Nuclear Fusion Journal Award is **F. Ryter**, for the paper "Experimental evidence for the key role of the ion heat channel in the physics of the L-H transition."

News from Fusion Science and Technology (FS&T) Journal, Nermin A. Uckan, FS&T Editor, Oak Ridge National Laboratory, Oak Ridge, TN.

The following is a summary of paper statistics and editorial activities for the ANS Fusion Science and Technology (FS&T) journal.

During the period October 1, 2016, to September 30, 2017, FS&T received a total of 141 manuscripts. During this period, there was large number of special issues. Papers rejected/withdrawn from pre-selection of conferences and special issues are not included in paper counts and regional breakdowns in the ANS/FS&T database.

Of the 141 manuscripts, 75 were from North America, 13 from Europe (including Russia), 48 from Asia, and 5 from others, with the following breakdown: 67 have been accepted, 36 have been rejected/withdrawn, and 38 are under review/revision.

The following dedicated issues were published during the period 10/1/16 to 12/31/17:

- APS Special Issue on Plasma Material Interactions – FS&T (Jan 2017)
- Selected papers from Tritium 2016 – FS&T (Apr. & May 2017)
- Selected papers from TOFE2016 – FS&T (Oct. & Nov. 2017).

The following issues are scheduled/planned for 2018:

- Selected papers from the 22nd Target Fabrication Meeting – FS&T (scheduled for March & April 2018; Bob Cook, Guest Editor)
- Selected papers from the 2nd IAEA-TM on Fusion Data Processing, Validation & Analysis – FS&T (scheduled for May 2018)
- Special issue on "Fusion Neutronics"– FS&T (planned for 2nd half 2018, Arkady Serikov, Guest Editor).

New with 2017: Starting with 2017, all three (3) ANS technical journals (Fusion Science and Technology, Nuclear Science and Engineering, and Nuclear Technology) are now being published by Taylor & Francis for the ANS. I have been serving as the Editor of FS&T since July 2001. It was a great privilege to serve for a professional society and the fusion community as a whole during the past 17 years. With the change to a commercial publisher, I have decided to step down from the editorship to allow others to serve as editor under this new arrangement. I am pleased that the ANS recently announced the appointment of Dr. Leigh Winfrey (University of Florida) as the new FS&T editor designate/editor. We all look forward to working with Dr. Winfrey as she begins her appointment as the editor in the new year 2018.

New in 2018: For all members, ANS is offering free searchable online access to the entire contents of current and archived issues of the Society's three technical journals: Nuclear Science and Engineering, Nuclear Technology, and Fusion Science and Technology. Don't forget to renew your membership and take advantage of this generous offer.

ONGOING FUSION RESEARCH

Recent DIII-D Contributions to the Scientific Basis for Fusion Energy,

M. E. Fenstermacher, Lawrence Livermore National Lab, Livermore, CA.

The DIII-D program continues to contribute to preparations for the operation of ITER and future fusion plants, with a focus on establishing the scientific basis for the optimization of the tokamak as a fusion energy device [1]. Following the themes of the 2015 U.S. national fusion program workshops, DIII-D experiments have, among a wide range of research lines, contributed to the understanding and control of transients in tokamaks, the advancement of fusion science and validation of integrated simulations for power plant predictions, and the control of Plasma Materials Interactions (PMI), including the optimization of tokamak divertor operation. Some examples of recent progress are discussed below.

Understand and Control Transient Events in Tokamaks

Optimization of tokamak plasma performance for power production requires establishing a transport barrier near the edge of the confined plasma. This High Confinement operating mode (H-mode) develops strong gradients of plasma density, temperature, and pressure at the plasma edge. This can drive Edge Localized Mode (ELM) instabilities, leading to periodic bursts of energy and particles out of the core plasma. In addition, the high pressure of the core plasma needed for efficient power production can lead to global instabilities that can abruptly terminate the plasma confinement, events known as disruptions. Both ELMs and disruptions must be strongly mitigated or eliminated in future power plants because the amount of energy and power released from these uncontrolled transients will severely damage the plasma-facing component (PFC) materials inside the device. For ITER, the frequency of the ELM bursts is estimated to be about 1 Hz, and estimates show that the ELM energy must be reduced by factors of order

20 to avoid PFC damage and long-term erosion issues over the lifetime of the device. The DIII-D program has a long history of contributions to control of these transients, see [1] and references therein, including recent results highlighted below. While the topics here focus largely on the issues of mitigating edge instabilities and plasma termination, further programs exploring control of core ideal and resistive instabilities have made good progress, including the development of techniques to establish stable regimes for ITER.

A. ELM Control

The DIII-D program focuses on three techniques for the control of ELMs in H-mode plasmas, vis.

1) By applying small 3D magnetic perturbation (3DMP) fields at the plasma edge to eliminate ELMs altogether (ELM "suppression");
2) By injecting small pellets of either cryogenically frozen deuterium or low-Z solids (e.g., Li or C) at high frequency to trigger very small, rapid ELMs (ELM "mitigation"); or
3) Setting conditions that allow the plasma to generate a very edge-localized magnetohydrodynamic (MHD) oscillation that produces enough transport to prevent the edge from reaching the gradients necessary to trigger the ELM instability ("No-ELM" Quiescent H-mode, QH).

ELM control systems for 3DMPs and pellet pacing are part of the design and operational plan of ITER.

Recent DIII-D experiments have continued to make progress on 3DMP ELM suppression. The 3DMP fields are produced with two toroidal rows of window frame coils (six per row) mounted on the inside of the tokamak vacuum vessel. ELM suppression has been established in DIII-D for plasmas with a standard H-mode core for many years [1]. Joint experiments with the ASDEX Upgrade (AUG) tokamak in Germany have led to the first successful suppression of ELMs using 3DMPs in that device, [2] and references therein. Those experiments showed very clearly that there is a strong dependence of the access to the ELM suppressed regime on the shape of the plasma, which is thought to influence the response of the plasma to these fields. Physics understanding of 3DMP ELM suppression mechanisms derived from the DIII-D research has also been used to help the EAST and KSTAR tokamaks suppress ELMs with their MP coils. In addition, suppression of ELMs has been recently extended to plasmas with a higher-performance core that would project to a more efficient fusion energy plant than with a standard H-mode core. Future work will both continue to increase the physics understanding of the mechanisms producing ELM suppression and extend the conditions under which suppression is maintained to those needed in future power plants.

Recent experiments on ELM mitigation by high frequency pellet injection [3] have shown nearly 100% triggering of ELMs by cryogenic D_2, with up to 6-8x frequency increase above the natural ELM frequency and a corresponding reduction in ELM target heat flux. Additional experiments extended these results to reactor-relevant low levels of torque input to the plasma, including the use of non-fuel Li pellets in anticipation of the need to reduce the load on the throughput of future plant fuel reprocessing systems. In the case of D_2 pellets at low torque there is a corresponding reduction of ELM energy, but ELM triggering by injection of Li pellets produced a mixture of ELM sizes up to the size of natural ELMs, for the low torque plasmas.

Finally, QH-mode research at DIII-D has also produced significant advances, including both physics understanding and extension of this "no-ELM" regime to conditions needed for future power plants [1]. QH-mode is a very attractive operating regime for future power plants because it displays high core confinement at stationary density and low radiated power, and it operates with no-ELMs without the need for hardware actuators. This "no-ELM" operational mode was originally discovered in plasmas with the injection of neutral beam heating in the direction opposite to the toroidal current in the plasma (Ip) – conditions not typically incorporated in designs of future power plants. Subsequent experiments proved QH-mode could be obtained with beams injected in the co-Ip direction. Recent QH-mode experiments, [4] and references therein, have shown that a bifurcation can occur in the nature of MHD modes in the edge that are key to QH access, which allows the transport barrier at the plasma edge to widen ("wide-pedestal") and the pressure at the edge to increase substantially. This bifurcation arises from moving toward a more reactor like rotation profile with reduced rotational shear. This leads to increased turbulence, relaxing the high edge pressure gradient slightly, which actually allows this high gradient region to grow in size and thus raise overall pressure. This would lead to projections of higher fusion power performance in plants operated with this "wide-pedestal" QH-mode edge regime.

B. Disruption Mitigation and Avoidance

The DIII-D disruption mitigation and avoidance program [1], has contributed significant insight into techniques to either reduce the effects of disruptions on PFCs or prevent disruptions before they occur. There is new scientific understanding of the mechanisms that lead to both toroidal and poloidal peaking of the heat flux to surfaces during disruptions, due to an instability that arises during this phase. Progress has been made on validation of non-linear simulations of these peaking factors, and new measurements with a novel gamma-ray imaging diagnostic have helped to validate models of the growth in populations of high energy runaway electrons (RE) generated during disruptions. Recently, there was a first demonstration of the dissipation of beams of these REs by injection of impurities into the plasma. This approach used a novel device that takes a frozen pellet of a deuterium-neon mixture and shatters it into a very large number of very small shards before injecting that aerosol into the plasma during the initial stages of the disruption, [5] and references therein.

Advancing Fusion Science and Validation of Integrated Simulations

A. Recent Fusion Science Results

It can be argued that all the research in the DIII-D program advances fusion science [1], but highlights from recent fundamental physics results concerning observed density limits, intrinsic toroidal plasma rotation, loss of confined ions by MHD modes, and the threshold power to get into the H-mode, show the diversity of these contributions. Experiments have provided data to support a proposed theory for the observed scaling of the maximum plasma density with the toroidal current in the plasma, as observed in many tokamaks over several decades. Experiments executed in collaboration with the JET tokamak have determined the scaling of the intrinsic toroidal torque on the core plasma with dimensionless parameters that allowed predictions of the intrinsic torque expected in ITER and future power plants. A model for the impact of injecting Electron Cyclotron Heating (ECH) power (a primary heating system planned for ITER) on the loss of energetic ions due to Alfven Eigenmode instabilities in the core plasma has been validated by experimental data. And as a final example, experiments have linked the mechanisms that determine the threshold power needed to trigger the bifurcation of the core plasma into the H-mode, with production of counter streaming MHD activity in the core ions and electrons.

B. Integrated Simulations Progress

The DIII-D program has a long history of advances in tokamak simulations, but one recent highlight showing progress on whole-device modeling involves the novel use of Neural Network (NN)–based models to couple simulations of the core and edge plasma behavior [6]. The recent models perform non-linear multivariate regression of theory-based models for the core turbulent transport fluxes and the structure of the steep gradient region at the plasma edge. The NN approach consistently reproduced the results of very sophisticated simulations from core and edge theory based codes, with a computational speedup of several orders of magnitude. This approach breaks the speed-accuracy trade-off expected from traditional numerical physics models. At the other extreme of the computational range, DIII-D is also using its comprehensive profile and turbulence diagnostics to test new multi-scale, multi-species turbulence simulations in which mode activity such as large-scale ion fluctuations can influence smaller scale electron fluctuations.

Control of PMI and Divertor Optimization

The DIII-D program is advancing the scientific basis for operation of tokamak divertors and PMI control needed for future power plants [1]. The carbon first wall in DIII-D allows great flexibility to explore the fundamental physics processes at the plasma material interface. It also aids manipulation of the divertor conditions for testing the physics mechanisms behind techniques needed to mitigate the excessive target heat flux predicted in future devices. Targeted campaigns also allow testing of reactor-relevant materials such as tungsten.

A. Detached Divertor Optimization Physics

The primary technique to achieve heat flux levels acceptable to divertor target materials in future devices is to detach the divertor plasma from the surfaces. This requires that significant volumetric radiation be produced sufficiently far from the surfaces that the radiated power can be spread over enough area to reduce the heat flux to levels the materials can handle. DIII-D experiments pioneered the understanding of divertor detachment physics, due in part to the only Thomson Scattering measurement of the electron density and temperature in any divertor worldwide. Recent experiments have extended the physics understanding of detached divertors and validated fluid code simulations of detachment by measuring the dependence on magnetic field direction–dependent particle drifts in the divertor region. The critical role of plasma flows and drifts are identified in behavior, which may explain a bifurcation to detachment. Further experiments made progress on validating the detailed radiation physics models for the very-high-density, low-temperature plasma conditions in detached tokamak divertors.

B. Effect of Tungsten Targets

For many years, there have been small sample tests of candidate high-Z metallic reactor-relevant target materials in DIII-D using a divertor materials exposure apparatus, but recent experiments were performed with full toroidal rings of tungsten (W) target surfaces to test models of high-Z material sourcing to the plasma around the periphery of the chamber, transport from the source to other regions of the device, and contamination in the core plasma. Results [7] showed that the W sputtering profile was driven by a combination of ELM effects, carbon ion flux, and magnetic field–dependent particle drifts. With high-energy ELMs, the W transport in the periphery plasma was also strongly dependent on ELM size and frequency. Finally, core W accumulation could be prevented by injecting ECH power into the plasma center.

Summary and Conclusions

Recent experiments in DIII-D have contributed to the scientific basis for fusion energy by increasing the understanding of mechanisms driving key challenging elements of scenarios for future fusion power plants, vis. the control of transient events that are predicted to produced damaging levels of heat and particle fluxes to the PFCs in future devices, the advancement of basic fusion science toward the ability to do whole-device predictive modeling, and the control of processes at the PMI interface in the divertor of tokamak designs. The observations described here represent a small proportion of physics studies on this national facility. Upgrades are planned for the device that will assure that similar important contributions to fusion energy development can continue at DIII-D for many years, by advancing research capabilities further toward the challenges that must be met for future power plants.

References:

[1] W. M. Solomon et al., "DIII-D Research Advancing the Scientific Basis for Burning Plasmas and Fusion Energy," Nuclear Fusion, **57**, 102018 (2017).

[2] R. Nazikian et al., "First Observation of ELM-Suppression by Magnetic Perturbations in ASDEX Upgrade and Comparison to DIII-D Matched-Shape Plasmas," 26th IAEA Fusion Energy Conference Kyoto, Japan, Oct. 22 (2016).

[3] A. Bortolon et al., "Effectiveness of high-frequency ELM pacing with deuterium and non-fuel pellets in DIII-D," submitted to Nuclear Fusion (2017).

[4] Xi Chen, K. H. Burrell et al., "Bifurcation of Quiescent H-mode to a Wide Pedestal Regime in DIII-D and Advances in the Understanding of Edge Harmonic Oscillations," Nuclear Fusion, **57**, 086008 (2017).

[5] D. Shiraki et al., "Shattered Pellet Injection as the Primary Disruption Mitigation Technique for ITER," Proceedings of the 26th IAEA Fusion Energy Conference, paper EX/9-2.

[6] O. Meneghini et al., "Self-consistent core-pedestal transport simulations with neural network accelerated models," Nuclear Fusion, **57**, 086034 (2017).

[7] T. Abrams et al., "Understanding tungsten divertor sourcing and transport in DIII-D high performance discharges," to be submitted to Nuclear Fusion (2018).

CALENDAR OF UPCOMING CONFERENCES ON FUSION TECHNOLOGY*

2018:

ANS Student conference
April 5-7, Gainesville, FL, USA
http://ansstudentconference2018.com

ANS Annual meeting
June 17-21, 2018, Philadelphia, PA, USA
http://www.ans.org/

23rd International Conference on Plasma-Surface Interactions in Controlled Fusion Devices (PSI 2018)
June 17-22, 2018, Princeton, NJ, USA
https://psi2018.princeton.edu

30th Symposium on Fusion Technology (SOFT)
September 16-21, 2018, Giardini Naxos, Italy
http://www.soft2018.eu

16th International Conference on Plasma Surface Engineering (PSE 2018)
September 17-21, 2018, Garmisch-Partenkirchen, Germany
https://www.pse-conferences.net/pse2018.html

6th International Conference on Nuclear and Renewable Energy Sources (NURER)
September 30-October 3, Jeju Island, Korea
http://nurer2018.org

27th IAEA Fusion Energy Conference (FEC)
October 22-27, 2018, Ahmedabad, India
Fusion-Physics@iaea.org

60th American Physical Society - Division of Plasma Physics (APS-DPP) meeting
November 5-9, 2018, Portland, OR, USA
http://www.apsdpp.org/meetings/upcoming_meetings.php

ANS 23rd Topical Meeting on the Technology of Fusion Energy (TOFE)
November 11 -15, 2018, Orlando, FL, USA
winfrey@mse.ufl.edu

ANS Winter meeting
November 11 -15, 2018, Orlando, FL, USA
http://www.ans.org/

2019:

12th International Conference on Tritium Science and Technology (TRITIUM 2019)
April 22-26, 2019, Busan, S. Korea

17th International Conference on Plasma-Facing Materials and Components for Fusion Applications (PFMC-17)
May 20-24, 2019, Eindhoven, The Netherlands

ANS Annual meeting
June 9-13, 2019, Minneapolis, MN, USA
http://www.ans.org/

28th IEEE Symposium on Fusion Engineering (SOFE 2019)
June 10-13, 2019, Atlanta, GA, USA

14th International Symposium on Fusion Nuclear Technology (ISFNT)
September 23-27, 2019, Budapest, Hungary

11th Inertial Fusion Sciences and Applications (IFSA-2019)

61st American Physical Society - Division of Plasma Physics (APS-DPP) meeting
October 21-25, 2019, Ft. Lauderdale, FL, USA
http://www.apsdpp.org/meetings/upcoming_meetings.php

19th International Conference on Fusion Reactor Materials (ICFRM)
Oct. 27 – Nov. 1, 2019, La Jolla, CA, USA

ANS Winter Meeting
November 17-21, 2019, Washington, DC, USA
http://www.ans.org/

* Calendar of other meetings (of interest to researchers in atomic, molecular and plasma-material interaction processes and data relevant to plasma physics and fusion energy research) are posted at: https://www-amdis.iaea.org/w/index.php/Calendar_of_Meetings.