Advanced Materials Validation in Toroidal Systems for Next-Step Devices

Zeke Unterberg, Oak Ridge National Laboratory
for the Boundary/PMI Center Team at the DIII-D National Fusion Facility

Plasma-material interactions (PMI) remain one of the most critical challenges for fusion reactors. Viable plasma facing components (PFCs) must be developed for next step device and are a universal challenge to fusion energy, regardless of confinement concept. Candidate materials should: 1) eliminate or reduce core contamination and/or dust production due to erosion; 2) have reasonable lifetimes under high heat, particle and neutron bombardment; and 3) minimize tritium retention. These challenges are spelled out clearly in Thrust 10 of the 2009 ReNew Report and have been flagged consistently since this report as a preeminent gap in fusion research. A national initiative to develop these materials and components is needed, especially now as we enter into the ITER era of fusion energy development and prepare for the design of a Fusion Nuclear Science Facility.

Focused research combining toroidal confinement experiments and linear materials testing facilities provides integrated systems testing of materials and components, including exposure to off-normal plasma events and a broad spectrum of plasma energy and particle-fluxes. Short-pulse, toroidal devices (~ 10sec), in particular, add further benefit by providing an experimental environment that is relatively easy to access and comprehensively diagnose than are long-pulsed toroidal devices. This is especially important for initial component development (e.g., at TRL3+) where quick turnaround and detailed measurements are desirable for multiple materials and/or components prior to a long-pulse systems test. The DIII-D National Fusion Facility is preparing to address this challenge as part of a national PMI research initiative by providing a flexible, well-diagnosed environment for materials evaluation and integrated testing. This should assist a goal-driven effort to develop novel, reactor-relevant PFC solutions for use in next step devices.

Towards this initiative, a major PMI/PFC research goal on DIII-D within 10 years is to implement a reactor-relevant PFC with materials and at temperatures necessary to begin component testing. Integrating this PFC regime with the advanced tokamak (AT) operating regime is a unique capability the DIII-D facility provides. A near-term research focus will be the quantitative study of migration of high-Z materials as called out as a high priority in recent panel committees; addressing this in a carbon PFC device where high-Z materials are truly trace elements is a unique-to-the-world quality of DIII-D. DIII-D will also work closely with linear devices to couple diagnostics that allow for the most direct cross-comparisons between these two geometries. Medium-term research goals will include integrating the techniques, diagnostics and understanding on PCF research with international long-pulsed devices.

This research program also enables strong engagement to the broader PMI community, including universities and national laboratories, through active participation/communication within e.g. the EPR (Exploratory Plasma Research) community among other avenues. This engagement addresses US fusion research needs beyond material research as it: 1) couples the excellent and unique talent and resources at all institutions; 2) provides an avenue for education and workforce development for a critical field in fusion research's future; and 3) provides a model environment for how the US could manage international collaborations in the future. Thus, it provides an excellent platform for US leadership in all these areas.

This initiative also integrates well into the OFES vision for the fusion research in the ITER era, i.e. the next ten-years and beyond. Specifically, the stated initiatives fit directly into two of the four newly developed program elements of OFES, i.e., *Burning Plasma Science: Foundations* and *Discovery Science*. In the *Foundations* category, the initiative fits with strong university partnerships, developing predictive capabilities, and addressing high-risk gaps in fusion research, while in the *Discovery Science* category, it addresses measurement innovation and plasma frontiers, as material research is a true frontier for fusion energy at this point. The OFES Director has highlighted each of these thrusts as the main components of the corresponding program elements.