Developing Heat Flux Solutions for Next-Step Fusion Devices

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The path towards next-step fusion development requires increased emphasis on the boundary/plasma material interface. In particular, a major challenge facing the design and operation of next-step high-power steady-state fusion devices is to control heat fluxes on the plasma-facing components (PFCs) including divertor and chamber walls (limited to a maximum steady-state power load of 10 MW/m2 for graphite and tungsten), to reduce material erosion to acceptable levels and minimize PFC damage due to steady-state and large transient loads. This poses an even greater challenge for FNSF with the envisioned Advanced Tokamak (AT) or Spherical Tokamak (ST) scenarios because of relatively low density (n/nGW ~ 0.6 for both cases) with respect to ITER (n/nGW ~ 1) and stringent needs to separately control divertor and core parameters. It is therefore urgent to find viable boundary/PMI solutions with adequate core plasma performance, which can lead to an attractive fusion power plant. To respond to this challenge, we have established a new Boundary/ Plasma-Material Interactions (PMI) Center at the DIII-D National Fusion Research Facility with the initiative to address critical PMI issues for fusion in the ITER era. In order to develop and validate robust heat flux solutions for future fusion devices, the Center intends to pursue the following transformational approaches on a timescale relevant to the design of FNSF (Fig. 1):

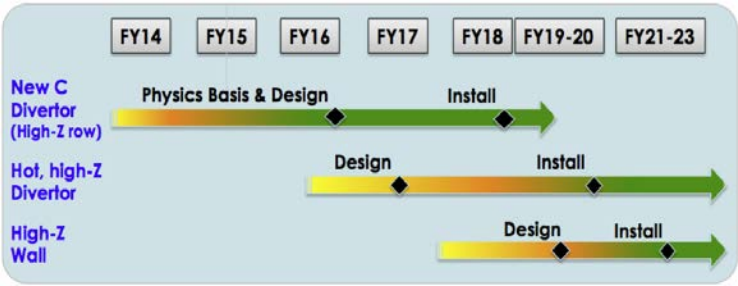

Fig. 1. Timeline of DIII-D Boundary/PMI Approaches

- Develop and test advanced divertor configurations on DIII-D, which are compatible with the core plasma high performance operational scenarios in FNSF. This entails the development of validated predictive models for detachment, exploration of advanced divertor geometry with flexible magnetic configurations, accompanied by an extensive diagnostic set to determine the underlying physics processes.
- Validate candidate reactor PFC materials, at reactor-relevant temperatures, in DIII-D high-performance plasmas, in collaboration with the broad material research/development community.
- Integrate validated boundary-materials interface with high performance plasmas to provide viable boundary/PMI solutions for next-step fusion devices.

This initiative leverages not only unique DIII-D capabilities, but also strong, broad collaborative efforts within the DIII-D and DiMES PMI research programs. DIII-D has developed a flexible magnetic configuration with readily modified divertor hardware, and robust plasma control systems. In addition, DIII-D possesses world-leading divertor and boundary diagnostics, including the unique two-dimensional Thomson scattering and flow measurements, enabling detailed assessment of intricate boundary/PMI physics. We envision further augmentation of the boundary and divertor diagnostic capabilities in support of this initiative. This, coupled with strong boundary computational effort, allows for validating models and providing relevant data, in a realistic fusion environment, to the broad PMI community with expanded domestic and international collaborations.

The major thrust of this initiative aims at addressing the challenge facing power and particle handling under high performance and advanced tokamak conditions, which is not only of great value to ITER, but will also explore physics and technology for FNSF and next-step devices. This initiative takes advantage of existing capabilities of the DIII-D boundary/PMI program, promotes synergistic programs within the broad PMI community, including linear material research facilities. It will enable us to build a compelling bridge for the US research on long-pulse facilities and will enable US to become a forefront international leader in this critical area.