Develop the basis for PMI solutions for FNSF
David N. Hill, Lawrence Livermore National Laboratory

With fusion research entering the ITER burning plasma era, a transformation of the Fusion Energy Sciences program over the next decade is expected, leading to starting design of a Fusion Nuclear Science Facility (FNSF) that will provide a fully integrated, continuously driven nuclear fusion environment. A key enabling step in designing this device is the development of Plasma-Material Interface (PMI) solutions that meet stringent heat flux and erosion mitigation requirements, as noted by previous FESAC panels. The thin scrape-off-layer (SOL) and associated divertor plasma must dissipate the heat and particle flux coming from the fusion core while providing boundary conditions supporting the required fusion gain. Studies show that the majority of the fusion-alpha heating power must be dissipated before the plasma reaches the first wall to reduce material erosion to acceptable levels and avoid surface melting. The quantitative predictive scientific basis for meeting this challenge remains to be established. We propose three Solution-Based Science initiatives that will, over the next decade, provide the scientific and technology basis necessary to begin design of a FNSF tokamak:

1. **Develop robust plasma-based solutions to meet the PMI challenges posed by FNSF.** Experiments have shown the feasibility of reducing surface heat flux and material erosion through recycling control and divertor detachment (edge/divertor radiation + volumetric recombination leading to a partially detached plasma). While the basic physical principles of detachment are known, the operating limits and quantitative physics basis for achieving robust control in FNSF and DEMO are not in place. Novel divertor configurations (e.g., Snowflake, Super-X) offer the potential of reducing target-plate heat/particle flux significantly but have yet to be fully qualified for use in next-step devices. Given the complexity of the problem, now is the time for an initiative to establish the requisite predictive boundary physics basis needed to design divertors and plasma-facing components for burning plasma experiments. This initiative would combine expanded coordinated multi-machine experiments on existing tokamaks featuring divertor configuration flexibility and comprehensive 2D and 3D boundary measurements, with enhanced boundary simulation and model validation to meet the scientific challenge.

2. **Design, Develop, and Test Candidate Materials for Use as Plasma-Facing Components in FNSF.** Materials presently used for divertor and main chamber walls (tungsten, lithium, carbon, beryllium, molybdenum) may not be suitable for steady-state burning plasma experiments. New materials (alloys, compositions), surface treatments, or fundamental component designs must be developed and tested. Advances in materials science and new large-scale computational capability make it timely for an initiative to engage the materials science community to develop relevant fusion PFC materials and component technologies. Materials science laboratories and linear plasma test facilities that simulate conditions expected in fusion devices offer a cost effective path for initial development activity. The ability to test samples exposed to high neutron fluence in such devices would be beneficial. Sample and component testing in existing tokamaks, with their well diagnosed plasmas, will be crucial to test the material response, validate models, and examine interaction with high performance core plasmas.

3. **Pursue Core-Edge Physics and Operational Integration to Inform the FNSF Design Point.** The FNSF neutron fluence mission requires self-consistent solutions for the fusion core, plasma boundary, and plasma-material interface. Now is the time for an initiative to focus and increase efforts to evaluate core-edge integration using existing short pulse experiments featuring comprehensive diagnostics and configurational flexibility, and long pulse superconducting tokamaks that feature increasing power and pulse length. Tests should include advanced confinement regimes, control of transients, high power density SOL and divertor plasmas, and evaluation of relevant plasma facing material conditions, including temperature and sufficient discharge length for the materials to reach steady-state conditions.

This work performed by LLNL for the USDOE under the auspices of contract DE-AC52-07N27344.