A Strategy for Resolving the Problems of Plasma-Material Interaction for FNSF

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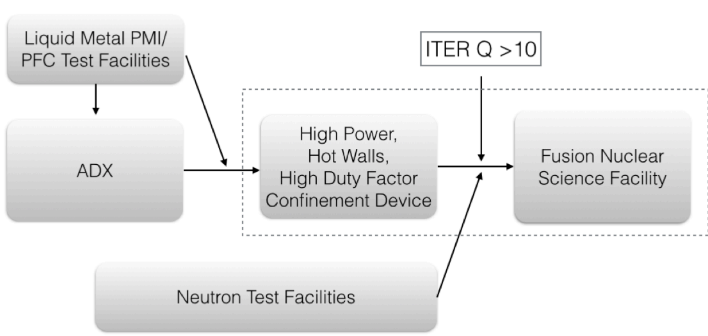
Arguably the greatest barrier to the development of commercial fusion energy is the problem of plasma-material interaction. While ITER will begin to address these issues, it will do so in conditions that are far from those of a commercial fusion power plant in terms of 1) heat and particle fluxes, 2) wall temperature, 3) duty factor and 4) neutron irradiation. ITER also uses PFC technologies such as a Be first wall and water-cooled W divertor that are not applicable to a power plant. Moreover, recent results indicate that the heat and particle flux challenges for FNSF will be more severe than anticipated even a few years ago. The development of advanced divertor geometries and advanced divertor target and first-wall materials will be required. Steady-state tokamak reactors will also require the development of low-PMI, RF-based current drive and heating schemes.

Plasma-facing materials and components face two major threats: plasma exhaust fluxes, and neutron irradiation. Because energetic neutrons typically penetrate ~ 10 cm into materials, while plasma exhaust interacts directly only with the first few microns of a surface, neutron irradiation modifies bulk material properties but has little direct effect on plasma-material interaction. Thus it is possible to make progress on these two threats in parallel, as shown in the figure below.

This strategy requires a near-term component of aggressive use of existing world-wide PMI/PFC test facilities for solid materials, as well as new U.S. facilities designed for testing liquid metal materials and components. It is also necessary to demonstrate integrated PFC and advanced divertor configurations that are compatible with high-performance plasmas. The ADX proposal stands out as providing by far the highest parallel heat flux $\propto P_{SOL}B/R$ that could be available during this early time period, while operating at reactor-level magnetic fields and providing the most flexible divertor geometry. In addition the facility would have an unprecedented ability to test high-field side launch RF heating and current drive schemes – a potential game changer for efficient low-PMI RF systems. ADX would be complemented by the EAST and KSTAR devices, which are planned to provide longer pulses, albeit at low duty factor; these devices will not have the high parallel heat flux nor the divertor magnetic geometry flexibility of ADX. Exploratory PMI research will be provided by NSTX-U and DIII-D. While NSTX-U, DIII-D, EAST, and KSTAR will help address PMI/divertor issues, unlike ADX their parameter range of operation (parallel heat flux, magnetic field, plasma pressure at the boundary) will not reproduce the reactor-level plasma and atomic physics parameters that will control divertor/PMI physics in FNSF. For this reason PPPL strongly supports the ADX proposal. (If ADX moves forward, PPPL would partner with MIT on the project, contributing to engineering, diagnostic and auxiliary heating development, and ultimately playing a major role in the scientific research team.) In the mid-term a confinement device capable of operating at very high heat and particle flux, with reactor-like wall temperature and high duty factor will be required to develop fully integrated solutions; its divertor geometry and PFC materials would be informed by ADX. (In principle this mid-term mission could be accomplished in the first phase of an FNSF, at the price of additional risk. This decision can be taken at a later date in the plan.) In the final step of the plan, the results from PMI test facilities and confinement devices are combined with the results from neutron test facilities to support the construction of a Fusion Nuclear Science Facility at the earliest practicable date, likely when ITER achieves Q > 10. If development of the needed science and technology in other areas is completed by this time, in particular blanket technology, FNSF could put a modest amount of fusion electricity onto the grid starting in ~ 2040.



New U.S. facilities needed for PMI/PFC development.
A strong program in theory and modeling is also required.