Successful completion of Alcator C-Mod, and the transition to a new, advanced divertor facility (ADX) to solve key challenges in PMI and development of the steady-state tokamak

Maintaining world-leadership on the high magnetic field path to fusion

The Alcator national team is poised for critical advances in plasma sustainment with RF, plasma-material interactions with all metal walls, and intrinsically ELM-suppressed high confinement regimes. On C-Mod, we will resolve the challenges of ICRF-induced impurities, understand the limits on Lower Hybrid Current Drive (LHCD) at reactor-relevant densities, and elucidate the extrapolation of enhanced energy confinement regimes which do not require ELMs for particle and impurity control. In parallel we will complete the design of the next logical step in high magnetic field, high power density research, a facility (ADX) to solve the reactor power-handling challenges with advanced divertors, and to develop the reactor-relevant RF tools required to maintain the tokamak configuration.

E. Marmar, on behalf of the Alcator Team

Alcator C-Mod is unique in the world. It is the only divertor tokamak which simultaneously operates at reactor-appropriate magnetic field (5 to 8 T), density (1 to $3x10^{20}$ m^{-3}), power density (P/S~$1MW/m^2$, PB/R~60MW-T/m), using RF heating and current drive tools (low-torque, particle source-free), with dimensionless core plasma parameters matching those of the larger, lower field devices in the world. The Alcator team continues to be highly productive on the international stage (most publications/$ and most citations/$ over the last 5 years, 2 of the 4 most recent Nuclear Fusion prizes for outstanding publication, including in 2013). Key near-term C-Mod research will include ICRF, LHRF, SOL, PMI, and disruption mitigation, to inform ITER and FNSF. Among the highest priorities are assessment of the full potential of the high-Z vertical plate divertor at reactor level power density and neutral opacity, in support of ITER, and comparisons with accessible advanced divertor configurations (snowflake, X-divertor) in the same device. Two critical facility upgrades are ready for installation: an off-axis LH launcher, to double the total current-drive power and make definitive tests of off-axis launch, for greatly enhanced LHCD efficiency to access fully non-inductive AT scenarios at reactor-relevant densities; a second field-aligned ICRF antenna to provide maximum plasma heating with minimum high-z impurity contamination. Continued operation of C-Mod will also lead to vastly improved understanding of the enhanced confinement, ELM-free I-mode regime. Understanding the underlying pedestal dynamics will be key to answering the question of extrapolability to ITER and FNSF.

Two of the highest priority gaps identified by FESAC[1] are the challenges of plasma-material interactions (PMI) and steady-state sustainment of the tokamak. Current facilities, (both domestic and international) will not be able to address several of the key related questions in the next 10 years. We need a new confinement facility. Leveraging the technology developed for C-Mod (jointed high-field magnets, ICRF and LHRF), combined with the experience and expertise of the national C-Mod team, we propose the Advanced Divertor eXperiment (ADX). As demonstrated by the Alcator program, a high-field, high-power density, compact tokamak is the ideal platform to produce reactor-level magnetic fields (B) and parallel heat flux densities ($q_{//}$) in the boundary layer. With a suitable arrangement of poloidal field coils, a compact, high field, high power density ADX can be constructed to simulate and compare a number of advanced divertor concepts at FNSF/DEMO conditions. High-field side RF launchers, which preliminary studies show can provide substantially improved current drive performance, can be integrated into the design. Pulse lengths of 3 to 5 seconds are ideal for the primary mission: *identify reactor-relevant plasma exhaust, current drive and PMI physics solutions that extrapolate to steady state, compatible with achieving a burning plasma core*. Results can be reliably projected to long-pulse because over a 3-5 s pulse length, steady power and particle exhaust, steady ion-impact and material erosion/redeposition fluxes and fully relaxed current profiles are well established. Relatively inexpensive cryogenically cooled copper magnetic technology can be used and the cost/complexity of steady state cooling is avoided. The result is a small, highly flexible ADX that capitalizes on unique strengths in the US fusion program: world-leading experts in advanced magnetic divertors, liquid metal target concepts and RF physics combined with the high-field magnet technology and high power-density RF systems developed in the Alcator program.

To date, C-Mod has trained over 170 graduate students. The completion of the C-Mod mission and the transition to ADX will keep this vital pipeline open, helping to ensure future world leadership in the US, for ITER and beyond.

We are ready now to proceed with detailed design of ADX. Construction would begin when the critical C-Mod research is completed. ADX success will be a key intermediate step on the attractive, cost-effective path to a high-field FNSF/Pilot Plant[2].

[1] Priorities, Gaps and Opportunities: Towards A Long-Range Strategic Plan For Magnetic Fusion Energy, FESAC Report, October, 2007
[2] Smaller and Sooner: How a new generation of superconductors can accelerate fusion's development, D. Whyte, et al, FPA Meeting, 2012