Status of preparations for a polarized-fuel demonstration experiment in the DIII-D tokamak

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As has been known for some time, the cross section for the primary fusion fuel in a tokamak reactor, $D + T \rightarrow \alpha + n$, would be increased by 50% if the fuels were spin polarized parallel to the local field. New simulations predict additional non-linear gains from increased alpha-particle heating in large-scale machines such as ITER, leading to a potential 75% power increase. These are significant enhancements that could lower the requirements needed to reach ignition and could be used to extend useful reactor life by compensating for neutron degradation of critical components. The potential realization of such benefits rests on the survival of spin polarization for periods comparable to the energy containment time. Interest in polarized fuel options had an initial peak of activity in the 1980s, where calculations predicted that polarizations could in fact survive a plasma environment. However concerns were raised regarding the cumulative impacts of plasma refueling from the reactor walls. In addition, the technical challenges of preparing and handling polarized materials prevented any direct tests. Over the last several decades, this situation has changed dramatically. Detailed simulations of the ITER plasma have projected negligible plasma refueling from the tokamak walls in a high power reactor. In addition, a combination of advances in three areas - polarized material technologies, polymer pellets for Inertial Confinement (ICF), and cryogenic tokamak injection guns - have matured to the point where a direct *in situ* measurement is possible. Our collaboration is developing designs for a proof-of-principle polarization survival experiment using the isospin mirror reaction, $D +^3 He \rightarrow \alpha + p$, at the DIII-D tokamak in San Diego[1,2]. Polarized deuterium, in the form of solid molecular HD, and polarized ^{3}He gas will be prepared for injection in separate ICF shells. The ^{3}He must be polarized first and then permeated through the polymer of the shell wall; the permeation and polarization properties of ^{3}He in ICF shells are now actively being studied using Magnetic Resonance Imaging. In an envisioned test in DIII-D, separate pellets of HD (with 40% D polarizaiton) and ^{3}He (polarized to 65%) can be injected into a high-performance Quiescent H-mode hydrogen plasma, with temperatures comparable to the projected ITER plasma. The resulting energetic protons from fusion will have large gyro-radii and will rapidly leave the plasma and be detected at several wall locations. Radio frequency manipulations can be used to orient D and 3He spins in either parallel or antiparallel configurations. Assuming fuel polarization survival as expected, a 30% enhancement is anticipated in the ratio of proton yields for plasma shots with fuel spins parallel and antiparallel. Detailed tracking simulations for the DIII-D tokamak have been performed and have projected a significant dependence on poloidal angle, providing an important additional constraint on systematics in such a test experiment.

[1] D.C. Pace, M.J. Lanctot, G.L. Jackson, A.M. Sandorfi, S.P. Smith and X. Wei, J. Fusion Energy **35** (2016) 54.
[2] A.M. Sandorfi, A. Deur, C, Hanretty, G.L. Jackson, M. Lanctot, J. Liu, M.M. Lowry, G.W. Miller, D. Pace, S.P. Smith, K. Wei, X, Wei and X. Zheng, arXiv:1703.06165 (2017).