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Conceptual design of DIII-D experiments to diagnose the lifetime of spin polarized fuel

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The D-T fusion cross-section in magnetically confined plasmas is increased by 50% when the spins of both nuclei are polarized along the magnetic field[1], offering promise for a significant increase in fusion energy output with no additional requirement on plasma confinement. Theoretically [1], depolarization mechanisms from field inhomogeneities or collisions are weak in the core of a tokamak but the polarization lifetime has never been measured. The goal of this study is to assess the feasibility of lifetime measurements on the DIII-D tokamak using relative changes in charged fusion product (CFP) loss measurements that depend upon the differential fusion cross section $d\sigma/d\Omega$. Relative measurements are preferred over absolute measurements of the total reaction rate for two reasons. First, changes in relative measurements with polarization are insensitive to uncertainties in plasma parameters, while the reaction rate is not. Second, $d\sigma/d\Omega$ changes when only one species is polarized but the cross section does not. Relative changes in the escaping CFP pitch, poloidal, and energy distributions are all sensitive to changes in $d\sigma/d\Omega$.

Three scenarios are considered. In the first, a tensor-polarized deuterium pellet is injected into an L-mode hydrogen background plasma that includes neutral beam injection (NBI) of unpolarized deuterium and compared to an unpolarized pellet of similar size and velocity. The effect of polarization on $d\sigma/d\Omega$ is controversial for D-D but almost certainly is non-zero [2], so the persistence of changes in 3-MeV proton signals yields a lifetime measurement. The second scenario substitutes unpolarized 3He NBI for D NBI and utilizes both 15-MeV proton and 3.7-MeV alpha detection. In nuclear physics, D-3He and D-T are nearly identical mirror reactions, so the expected change in $d\sigma/d\Omega$ is well known. In the third scenario, vector-polarized D and 3He pellets are injected into a hot hydrogen plasma to produce thermonuclear reactions.

The calculations utilize realistic plasma scenarios from TRANSP and energy-resolved CFP count rates evaluated with FIDASIM [3]. Initial results for the D-D scenario show that the pitch and energy distributions of 3-MeV protons are sensitive to changes in $d\sigma/d\Omega$ for a port on the midplane; signal levels are also practical.

[1] R.M. Kulsrud et al., Nucl. Fusion 26 (1986) 1443.

[2] H.M. Hofmann and D. Fick, Phys. Rev. Lett. 52 (1984) 2038.

[3] W.W. Heidbrink et al., Plasma Phys. Control. Fusion 63 (2021) 055008.

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Speaker's Affiliation

University of California, Irvine

Member State or IGO

United States of America

Authors: GARCIA, Alvin V. (University of California, Irvine); HEIDBRINK, William W. (University of California Irvine); Dr SANDORFI, Andrew (Jefferson Lab)

Presenter: GARCIA, Alvin V. (University of California, Irvine)

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