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Performance of laser-polarized 3He in tokamak fuel pellets

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Nuclear fusion has long been considered an ultimate solution for clean energy production. Despite decades of research, ignition, or self-sustained energy production, has been elusive. The use of spin-polarized fuel in a tokamak reactor would provide a significant boost. The cross section for the D + T ⟶ α + n reaction would be enhanced by 50% if the deuterium and tritium nuclei were fully polarized along the local magnetic field. Realizing such benefits requires the polarization to survive in the plasma environment for the energy containment time. A multicenter collaboration, including Jefferson Lab, University of Virginia, and DIII-D/General Atomics, is planning the first direct test in the DIII-D tokamak in San Diego, using the mirror reaction D + 3He ⟶ α + p. This proof-of-principle experiment would use inertial confinement fusion (ICF) pellets containing either hyperpolarized D (in the form of solid HD) or hyperpolarized 3He, which would be injected directly into the plasma core. ICF pellets are polymer shells that can be filled by permeation at elevated temperatures and sealed by cooling. While deuterium can be permeated through the shell wall and then polarized using standard nuclear physics protocols, 3He must be polarized first (e.g. by spin-exchange optical pumping) and then permeated through the shell wall. To be useful, the 3He polarization must survive permeation and have a sufficiently long spin-relaxation time (T1) within the shell. In this talk, we present preliminary results on ICF pellets filled with laser polarized 3He, using data acquired with a clinical 1.5-T magnetic resonance imaging (MRI) scanner. A 0.5-mm spatial resolution, which is sufficient for resolving the 2-mm diameter pellets used in this study, was achieved by using specially designed RF coils and MRI pulse sequences. Permeation loss at room temperature was extracted from a time series of 3He images, by comparing the signal magnitudes inside and
outside a pellet. An absolute calibration was obtained by imaging a room-temperature mixture of 3He and O2 at thermal equilibrium polarization. Spin-relaxation times were measured over a range of holding temperatures. The T1 of a polarized 3He pellet cooled to 77K is greater than 6 hours, which is sufficient for the planned tokamak experiment.

Presenter: MILLER, Wilson (University of Virginia)

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