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SOLPS-ITER Modeling of Low Recycling Divertor Solutions for the Spherical Tokamak Advanced Reactor (STAR)

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A large driver of future fusion reactor size is the need to handle transient events that could potentially cause re-attachment, which pushes the capabilities of conventional divertors [1]. Liquid metals are an attractive solution to transients due to vapor shielding [2] whereby the temperature of the plasma facing component (PFC) becomes clamped even at excessive plasma heat fluxes, such as those that would be experienced during the transient event. So long as the emission from the PFC can be limited [3], or the plasma flow can be controlled such that there is sufficient screening from the main plasma [4], liquid metals could minimally affect the upstream plasma. Recently, a variant of the lithium vapor box divertor concept [3,5] has been proposed for NSTX-U, only requiring a small evaporating region in the private flux region (PFR) to control the target heat flux. Furthermore, a Capillary Porous System with Fast flowing liquid lithium (CPSF) [7] has been proposed as a potential PFC, with SOLPS-ITER modeling indicating steady state peak target heat fluxes of 18 MW/m2 could be handled with PFC peak temperature ~715℃ in NSTX-U [3]. Modeling of these concepts are hindered by the lack of certainty in the deuterium recycling rate, known to be high recycling at higher temperatures (~400℃), though with a strong dependence on the vessel pressure [8]. To demonstrate feasibility of these liquid lithium PFC concepts in a reactor and explore the effect of deuterium recycling reductions on the scrape-off layer, SOLPS-ITER is employed to model the Spherical Tokamak Advanced Reactor (STAR) [9]. STAR is a pilot plant concept, designed to take advantage of improved confinement from spherical tokamaks, while leveraging liquid metals to control the power exhaust. SOLPS-ITER results for STAR indicate that acceptable steady-state PFC temperatures can be achieved while handling PSOL > 135MW. The upstream impurity concentration resulting from employing these designs on STAR is found to vary significantly with the assumed divertor recycling coefficient. A temperature-dependent, radially varying model for the recycling is also introduced, which indicates a transition to a high-recycling regime above 350℃-400℃, in agreement with experimental data [8]. Combination with an external radiator is also tested and shown to have beneficial effects at controlling the upstream concentration of lithium, via reduced heat flux on the lithium PFC. Upstream lithium concentration ~0.02 is shown to be possible while maintaining Zeff ~ 2.4.

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