Progress in a US-based Liquid Metal Plasma-Facing Component Design Activity for a Fusion Nuclear Science Facility

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We report the results of a three-year US-based liquid metal divertor plasma-facing component (PFC) design program from 2019-2022. Three complementary and coordinated activities entail: (1) design calculations of heat transfer and liquid metal (LM) MHD flow for concepts designs applicable to a fusion nuclear science facility (FNSF); (2) test-stand experiments to close LM science and technology gaps; and (3) linear flow configuration experiments with applied magnetic fields to validate LM magnetohydrodynamic (MHD) models and test PFC designs. For design calculations, we model a general flowing liquid lithium (Li) PFC, with a 10 MW/m^2 incident heat flux removed by a thin flowing Li layer. The maximum surface lithium temperature is limited to 450°C, and gas cooling is provided on the back surface. We find that the most efficient heat transfer is via fast Li flow. The required flow speed to achieve 10 MW/m^2 heat flux removal is 5-10 m/s for an free surface concept, and also with a porous top surface to inhibit droplet formation. Modeling of plasma response with the SOLPS-ITER code evaluated different wall/boundary shapes, and concluded that Li was entrained in the divertor over a wide range of Li flux released due to plasma-material interactions. **Taken together, the MHD/heat transfer and plasma modeling indicate that a self-consistent design window exists for the FNSF input constraints.** For experimental activities, work was initiated on the design and construction of liquid Li fill injectors, flow loops, wetting studies, and corrosion and embrittlement studies, including material compatibility between liquid Li and reduced activation ferritic martensitic steel F82H. Finally LM MHD code validation experiments were initiated in the Liquid Metal eXperiment Upgrade (LMX-U), which investigates flowing (~1 m/s) Galinstan, a gallium compound, for flow uniformity and surface wave formation, hydraulic jumps, and heat transfer. Generally similar codes, or in some cases the same codes, used for FNSF design above quantitatively reproduced experimental trends, e.g. the reduction of flow speeds from conducting side walls that induce MHD drag in Hartmann layers. *Sponsored by Fusion Energy Sciences, Office of Science, U.S. Dept. of Energy.