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Computational Fluid Dynamics and Magnetohydrodynamics Analyses Supporting the Design of Water-cooled Liquid Metal Breeding Blankets for Magnetic Confinement Fusion Reactors

The Water-Cooled Lead Lithium (WCLL) is one of the two candidate breeding blanket (BB) concepts actively developed by the EUROfusion consortium for implementation in the European DEMO fusion reactor. DEMO is intended as a technological demonstrator aiming to substantiate the development of nuclear fusion as an energy source by supplying a power conversion system and operating a self-sufficient fuel cycle. The WCLL BB is seen as a promising candidate for near-term implementation due to its reliance on water cooling technology (of which significant experience is available in the nuclear fission industry) and the adoption of the eutectic alloy of lead lithium (PbLi) as a joint liquid-phase tritium breeder and carrier and neutron multiplier; indeed, the WCLL BB has been selected for testing in ITER within the Test Blanket Module experimental campaign.
This work provides an overview of the computational fluid-dynamics (CFD) and magnetohydrodynamics (MHD) analyses that have been performed in the Pre-Conceptual Design Phase (2014-2020) and are still ongoing in the Conceptual Design Phase (2021-2027) to support the development of the WCLL BB design. In particular, this presentation will be focused, without the pretence of being exhaustive, on three research lines that have been primarily pursued at Sapienza University of Rome. These are:
—CFD analyses to support and advance the design of the Breeding Zone (BZ) and First Wall (FW) cooling system in nominal and operational transient conditions. The activities have been focused on the design of the elementary Breeding Unit (BU) that constitutes a modular component repeated poloidally across the BB. Detailed analyses are performed for both the inboard and outboard BB segments at varying poloidal coordinate to account for differences in geometry and thermal boundary conditions;
—MHD analyses to investigate the flow of the liquid breeder under a strong applied magnetic field and characterize its thermal-hydraulic performance, specifically in terms of heat transfer coefficient and pressure loss. MHD flows both in the BU and the PbLi manifolds is characterized. Simplified numerical models are adopted to calculate the MHD pressure loss at reactor-scale;
—CFD and MHD analyses to simulate the prototypical behaviour of a pressurization transient due to the local ingress of the high-pressure water coolant in the high-temperature/low-pressure liquid breeder during a Loss-of-Coolant Accident. The main outcome is the preliminary characterization of the pressure transient both in ordinary hydrodynamics and MHD conditions providing insights about the response of the BB system during this design basis accident.
The presentation is also providing some insight into the development of numerical methods that are custom tailored for the development of water-cooled liquid metal BB and their validation process.

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