Abstract

Liquid metal breeding blanket designs are among the most promising concepts for future fusion reactors. In the Water-Cooled Lithium Lead (WCLL) breeding blanket the eutectic lithium-lead alloy is considered as tritium breeder and carrier. The dissolved tritium can permeate into the different structural materials, arising potential issues concerning the fuel self-sufficiency and can be lost into the environment with consequent radiological hazard for the population. Within this frame, a tritium transport analysis is fundamental to evaluate tritium retention in LiPb (15.7 at. % Li) and in the structures and tritium permeation fluxes into the cooling water. During the PhD activity, exploiting appropriate analytical and numerical tools, a portion of the breeder unit of the outboard and inboard equatorial module of the WCLL was analysed. A computational model was developed under COMSOL Multiphysics in order to simulate the complex phenomena of the WCLL. It considers buoyancy forces and the magnetohydrodynamic (MHD) effect and uses the output as input for tritium transport calculations. In this way, the permeated tritium to the structural materials and coolant and the inventories in the different domains were assessed. Analytical tritium transport models were developed for liquid metal systems, permitting the kinetics that regulates tritium transport and the concentration evolution and efficiency in tritium extraction systems. They have been compared to numerical models and applied to tritium extraction systems like Liquid-Vacuum Contactor (LVC). To support the numerical analysis, considering the uncertainties found in literature about tritium Sieverts' constant in lithium-lead, a laboratory device, called HyPer-QuarCh II, was developed to investigate tritium solubility in the liquid metal. Thorough analytical and numerical analyses were performed to support its design. Consistent Sieverts' constant values adopting different measurement techniques were obtained, highly increasing the reliability of the experimental results. The results obtained during the experimental campaigns with hydrogen and deuterium can be used to improve the fidelity of tritium transport calculations involving lithium-lead. Regarding tritium permeation, an extensive experimental activity was performed to characterize the performances of tritium permeation barriers made by alumina. The experimental campaigns results showed that such coatings can help to reduce the permeation of tritium in steel pipes. A WCLL mock-up to characterize alumina coatings

applied to pipes relevant for the breeding blanket was designed, that can be also used to validate numerical tools.