Plasma Facing Materials in fusion devices : when the 4 states of matter get together

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Developping nuclear fusion is one of the possible option for providing a carbon-free baseload energy source. Significant progress has been achieved over the last decades, and the international ITER project, presently under construction in Cadarache (France), is targeted at demonstrating the scientific and technical feasibility of fusion as an energy source.

The most efficient fusion reaction for energy production has been identified as the reaction between deuterium (D) and tritium (T), yielding a helium (He) nucleus and a neutron. In order to reach the extreme temperatures required for an efficient DT fusion reaction (~150 millions °C), the DT fuel is heated up to form a plasma —often referred to as the fourth state of matter. The most advanced configuration for containing this hot plasma is called a tokamak, in which magnetic fields are used to confine the charged plasma particles. The plasma facing materials are exposed to harsh conditions in fusion devices, both in terms of heat and particle loads stemming from interactions with the plasma. The boundary of fusion devices is a place where the solid plasma facing materials, using liquid based active cooling to handle heat loads, meet the fusion plasma as well as the gas resulting from plasma recycling on the walls, hence a place where the 4 states of matter get together. Taming the interactions between the solid walls of a fusion device and the plasma is a key issue for operating future fusion reactors.

This contribution will review the challenges for plasma exhaust in fusion devices, outlining how the plasma facing material evolves under plasma exposure. In particular, it will describe how to select adequate plasma facing materials, as well as how to design and operate plasma facing components (PFC) in a tokamak environment.

After a short introduction showing how fusion works and what the constrains on plasma facing components are, the focus of this presentation will be on describing the mechanisms involved in plasma wall interactions. This includes processes such as erosion of the wall material by the plasma (D/T/He and impurities) and subsequent wall material transport by the plasma, surface microstructural changes under plasma exposure, fuel trapping in the plasma facing material or dust production after erosion / deposition of the wall material. Both experimental and modelling aspects will be discussed.

The rationale for selecting a suitable plasma facing material will be presented. Due to its good thermo-mechanical properties and low activation behaviour under neutron irradiation, tungsten is presently identified as one of the most promising plasma facing material for future fusion reactors. ITER will operate with tungsten plasma facing components, both for the main chamber walls and the divertor, which is the most heavily loaded component in a fusion device. In order to prepare for a safe and reliable divertor operation in ITER, the WEST tokamak, run by the Institute of Research on Magnetic Fusion from CEA in Cadarache (France), has been recently equiped with an ITER grade divertor. The main findings from WEST in terms of material behaviour under plasma exposure in tokamak conditions will be presented. Finally, additional issues to consider for plasma material interactions in a future fusion plant will be discussed.