Contribution ID: **94** Type: **Oral**

Tungsten lifetime assessment for divertor component design

Wednesday, 9 November 2022 09:00 (20 minutes)

For the European fusion energy program, one of the main objectives is to establish a physical and technological basis for reliable power exhaust during the DEMOstrational power plant operation. As a consequence of the particles bombardment (ions, electrons, neutrals) coming from the plasma, the radiation, the energy conducted along the magnetic lines and from neutron irradiation, the divertor plasma facing components (PFCs) are the most thermally exposed. Considering these functional constraints, efforts are on-going to improve the material/component design and develop numerical codes which can achieve DEMO relevant Finite Elements (FE) simulations to assess tungsten damage and predict lifetime. Existing tools gave the opportunity to improve our understanding regarding the damage mechanism of such components under pure thermal heat flux. These simulations are representative to a number of existing fusion devices operational conditions but are not relevant for the DEMO operation. In that context, one goal of the T-REX project (funded by EUROfusion) is to provide for tungsten (used as armor material in the DEMO divertor PFC baseline) a FE modeling tool (based on ANSYS software) able to assess, at the macroscopic scale, the relevant mechanical stress and strain fields under DEMO operation conditions (plasma bombardment, conducted power, neutron irradiation).

The last T-REX developments are presented. For the first time, tungsten damage is assessed taking into account the influence of both isolated and combined heat flux/neutron loading on the tungsten thermal and mechanical properties (incl. the softening kinetics) and assess the Deuterium/Tritium (D/T) concentration profile considering the representative mechanical stress and strain fields estimated. Thermal cycling (10s ON/ 10s OFF) simulations are performed assuming a homogenous heat flux at either 10 or 20 MW/m² on the current DEMO divertor component design upper surface. Collected results show that thermal conductivity degradation (due to neutron irradiation) leads to temperature shifts (up to 400℃ at 20 MW/m²). As expected, this trend promotes the tungsten softening (recrystallization/restoration). Results highlight that softening occurs after only twenty thermal cycles at 10 MW/m², which is not expected under pure thermal load (w/o neutron irradiation). Besides, collected results highlight that the tungsten damage mechanism (ductile/brittle) depends strongly on the neutron fluence (dpa) and on the tungsten microstructural state (softened or not) under irradiation. Lastly, D/T concentration profiles obtained for tungsten under pure heat flux at 20 MW/m² (w/o irradiation) are given. This first application highlights the influence of the plastic strain increment generated after each thermal cycle on the D/T trapped in tungsten (which gives trends useful for safety).

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Session Classification: PFMC (part II)

Track Classification: Plasma Facing Component Materials and Heat Exhaust for Steady State Operation