Plasma wall interactions from a material perspective in fusion devices

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One of the outstanding issues facing the development of nuclear fusion power is the strongly coupled interaction of the edge plasma with the surrounding vessel wall where changes in one is reflected in the other by a feedback loop mechanism. From the plasma side, such interactions may lead to contamination of the plasma and fuel dilution due to impurities released from the materials. Additionally, recycling of hydrogen fuel from the walls has important consequences in density control of the plasma. From the material side, the large energy and particle fluxes result in changes to the material. This may result in unacceptable erosion or fuel retention resulting in a reduction in the component lifetime or an increase in the radiation hazard, respectively. Therefore, plasma wall interactions not only have an important role in determining the plasma performance, but also in setting the limits on the operational and radiation safety aspects of fusion devices. Consequently, the proper selection of materials to cover the vessel wall is a critical engineering decision that requires a clear understanding of how plasma facing materials interact with the plasma.

The principal aim of this lecture is to introduce students to the phenomena of plasma's impact on materials and its implications. It will first cover the basic physical processes between the plasma and the material wall. Principal investigations aimed at understanding such interactions from both present day fusion devices and laboratory experiments will be presented. Next, the three ITER materials of beryllium, carbon, and tungsten will be introduced. Specifically, the material response under: (i) heat loading, (ii) irradiation by energetic and thermal fuel species, and (iii) irradiation by helium and neutrons will be covered. The consequences of material mixing from the erosion, transport, and re-deposition processes will be discussed, as well as the need to evaluate the material response under all three simultaneous conditions above. The lecture will summarize the implication of the material modification on plasma performance. In closing, the challenges facing materials in fusion reactor conditions where the engineering criteria are significantly different from present day conditions will be presented.