How to predict and monitor tungsten net erosion in tokamak divertor?

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We lay out here theoretical principles to spectroscopically monitor tungsten net erosion in-situ in a tokamak divertor and review key parameters necessary to predict tungsten erosion and the subsequent divertor lifetime in ITER and future fusion reactors. In high-density attached divertor plasma conditions relevant for fusion reactors ($n_e > 10^{20}$ m\textsuperscript{-3}), the fraction of promptly redeposited tungsten impurities is large (~1) and determines the overall tungsten net erosion. The width of the electric sheath in a tokamak divertor is of the order of several main ion Larmor radii due to the magnetic field lines intersecting the material surfaces at grazing incidence \cite{D.D. Ryutov, Contributions to Plasma Physics 36.2-3 (1996): 207-219}, and a vast majority of sputtered tungsten impurities are ionized within the sheath region. In contrast, we show that only tungsten impurities which are ionized multiple times out of the sheath region do not redeposit. As a consequence, the fraction of tungsten impurities which do not promptly redeposit is directly proportional to the fraction of tungsten impurities which are ionized into the higher charge states 4+ and 5+. Therefore, the spectroscopic monitoring of the photonic emissions from tungsten atoms ionized into these high charge states provides an estimation of the amount of sputtered tungsten impurities that do not promptly redeposit and cause the net erosion of tungsten surfaces in divertor.

Besides, tungsten prompt redeposition is shown to be mainly governed by the ratio of the characteristic vertical ionization mean-free path of neutral tungsten over the width of the sheath. As a result, tungsten prompt redeposition is predominantly determined by tungsten ionization rates, the velocity distribution of sputtered tungsten impurities and the width of the sheath. Robust estimations of these quantities, validated against experimental observations, are required to predict the lifetime of the divertor in ITER and future fusion reactors. We review here existing uncertainties among those parameters and the experiments performed at DIIIID to address these uncertainties \cite{I. Bykov et al., this conference}. Likewise, effects and uncertainties in tungsten prompt redeposition and emissions due to metastable tungsten states are discussed \cite{C.A. Johnson, et al., Nuclear Materials and Energy (2019): 100579}. Finally, we examine the remaining issues in modeling of tungsten net erosion which must be addressed to deliver reliable predictions of tungsten divertor erosion and lifetime in ITER and future fusion reactors.

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\cite{I. Bykov et al., this conference}  
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