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Elements of the ITER tungsten divertor physics basis

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Building on about 20 years of physics simulation, engineering design work and component testing, the ITER divertor, the largest and most complex tokamak divertor ever to be constructed, is now well into the prototyping phase and is approaching full procurement. A first complete design review was already conducted in 2009, at that time featuring carbon fibre composite (CFC) monoblocks in high heat flux (HHF) areas. This divertor was to be used for the first "non-active" plasma campaigns in H and He, then exchanged for a full tungsten (W) variant before nuclear operation began. In 2013 the ITER Organization (IO) decided to eliminate CFC and design an all-W armoured divertor which would be installed from the start of operations and would be expected to survive until at least the end of the first major DT campaign. Over the past year, a new "4-staged approach" to nuclear operations has been developed, consistent with the ITER Members financial and technical constraints, in which first divertor plasmas will be produced at the beginning of 2029, to be followed by two campaigns of H/He operation and a series of nuclear campaigns starting from 2036 up to the beginning of 2041, by which time long pulse inductive and non-inductive operation at significant fusion burn will have been accomplished. The first ITER W divertor must survive this first ~12 year operational period.

Although the decision to switch to full-W was based on the solid foundation of many years of physics and engineering design for the CFC variant, all metal-PFCs present different challenges. In particular, the absence of natural carbon radiation requires the use of extrinsic radiators to ensure technologically feasible target power fluxes and W recrystallization and surface melting, due both to steady state and transient heat loads, have the greatest potential to compromise machine operation. These latter issues have driven the decision, based on a very significant, IO-driven R&D effort by the International Fusion Community over the past 3 years, to incorporate component shaping at the level of individual W monoblocks constituting the HHF areas, an additional complexity not considered for the CFC variant.

This talk will discuss the key areas of the physics basis for the ITER W divertor which have driven the design, focusing separately on steady state and transient power fluxes. The former are determined from simulations using the 2-D SOLPS-4.3 and SOLPS-ITER plasma boundary simulation codes, the IO workhorses for this assessment, assuming the use of the low Z extrinsic seeding impurities nitrogen and neon and now, for the first time, including fluid drifts allowing more realistic accounting for the in-out target power loading asymmetries. Work is also progressing, though at a slower rate, on the assessment of power loading in the presence of magnetic perturbations for ELM control, requiring a full 3-D plasma boundary modelling approach. In the case of transients, a new experimental scaling for ELM power deposition has shown that there may be more latitude for operation at higher current without ELM control than previously thought, but the ultimate limit may be set more by material fatigue under large numbers of sub-threshold melting events, issues of gap edge melting and W core contamination due to ELM impact. In the case of disruptions, recent simulations have shown that W vapour shielding may provide significant surface power flux mitigation at high energy densities.