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[REGULAR POSTER TWIN] Developments towards an ELM-free DEMO pedestal radiative cooling scenario in ASDEX Upgrade

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Due to the limited power exhaust capability of the divertor, a future DEMO reactor needs a high core/pedestal radiation level, controlled and tailored by an appropriate seed impurity mix. The core/pedestal seeding has to be integrated with substantial divertor radiative cooling and a no/very small ELM plasma regime. Required boundary conditions of the seeding scenario are sufficient energy confinement and low fuel dilution. Taking into account the radiative capabilities of the potential seeding species (N2, Ne, Ar, Kr, Xe), only Ar is expected to contribute substantially to both pedestal and divertor radiation for reactor conditions. Therefore, a likely scenario is the combination of Ar with Kr or Xe for core radiation at reduced dilution and with N2 or Ne for enhanced divertor radiation. For the divertor seeding species a high divertor impurity compression is also required to avoid excessive core dilution. This paper reports about recent studies in ASDEX Upgrade towards the development of corresponding DEMO seeding scenarios with emphasis on operation with no ELMs, good energy confinement, and compatibility with the tungsten plasma facing components.

One route to a no/small ELM scenario is the reduction of the edge pressure gradient in the steep gradient zone by radiative losses. Ar is particularly suited for AUG conditions since it creates a strongly radiating ring in the pedestal region. The radiation effect can be combined with additional pedestal transport effects as provided by turbulence or magnetic perturbations to assure ELM suppression. Recently, a new type of ELM-free H-mode with good energy confinement has been discovered at ASDEX Upgrade [1]. The scenario exhibits similarities with the EDA H-mode from Alcator C-Mod, a quasi-coherent electromagnetic mode with toroidal mode number n ~20 in the pedestal region results in complete stabilization of ELMs at good confinement. First attempts to combine this scenario with a feedback controller for the power flux over the separatrix via Ar seeding [2] showed ELM-free conditions at up to 5 MW injected NBI and ECRH combined power (figure 1, left panels).

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At higher power and core radiation, Psep could be kept low, in the vicinity of the H-L transition, but ELMs remained, albeit at reduced size (Fig 1, mid panels). Future studies are planned to determine whether a refined seeding strategy will allow for full ELM suppression also at high heating power. Figure 1 (right panel) compares the electron pressure gradient in the pedestal region with and without Ar seeding for H-mode discharges with and without ELMs. Indeed, Ar seeding reduces the maximum pressure gradient, while global confinement is even improved due to increased pressure further inwards.

A prerequisite for efficient divertor radiative cooling is the achievement of a high divertor impurity density compared to its core density, namely a high divertor compression. To shed light on the underlying processes, calibrated gas puffs of N2, Ne and Ar have been injected into ASDEX Upgrade H-mode plasmas for different values of the divertor neutral pressure. The temporal development of core densities and recycling rates was measured by charge exchange recombination spectroscopy, Zeff variations and a SPRED VUV spectrometer, see figure 2. The fastest removal rates are observed for Ar, shortening from ~ 0.3 to ~ 0.1 s as the divertor neutral pressure is increased from 0.6 to 4 Pa. At high pressure, the shortening saturates and Ne and Ar show equal pumping times. Such a shortening is not observed for N2, which appears to be dominated by wall storage and release processes.
Simple particle balance analysis allows already some conclusions. At very low pressure, pumping rates are expected to scale with the inverse square root of mass. At very high pressure, collisions with D2 molecules lead to an entrainment of the impurities in the D2 flow and equal removal rates for all species. The observed removal rates are proportional to the product of the divertor compression and the pumping speed. Faster removal rates of Ar vs Ne give evidence of a higher divertor compression of Ar vs. Ne. SOLPS calculation including the effects of neutral collisions are required for further quantification.

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In conclusion, Ar pedestal radiation is a promising tool for reduction of the pedestal electron pressure gradient, and thus an important element for a no-ELM scenario. Active control needs to be expanded towards the tailoring of the spatial profile of the radiation, rather than the pure radiated power. A step in this direction has recently been demonstrated for the X-point radiator regime in ASDEX Upgrade [3]. First attempts for combining core Ar radiation with RMP ELM suppression showed short (0.5 s) phases of good performance, but were hampered by the subsequent occurrence of a locked mode.

[1] L. Gil et al, Stationary ELM-free H-mode in ASDEX Upgrade', EPS 2019, submitted to Nuclear Fusion

[2] A. Kallenbach et al., Nuclear Fusion 52 (2012) 122003.

[3] M. Bernert et al., this conference.

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