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Alternatives to H-mode for EU-DEMO: what we know and what we need to know

M. Siccinio[1a,2], P. Barabaschi[3], T. Happel[2], J. Hillesheim[1b,4], A. E. Hubbard[5], A. Loarte[6], F. Liu[1b,7], H. Meyer[4], A. W. Morris[4], F. Parra[8], F. Ryter[2], O. Sauter[9], E. Viezzer[10], T. M. Wilks[5], H. Zohm[2]

[1] EUROfusion Consortium (a: Garching, Germany, b: Culham, UK) [2] Max-Planck-Institut für Plasmaphysik, Garching, Germany [3] Fusion for Energy, Garching, Germany, [4] Culham Centre for Fusion Energy, Culham, UK [5] Massachusetts Institute of Technology, Boston, USA,[6] ITER Organisation, Cadarache, France [7] CEA, Cadarache, France [8] University of Oxford, Oxford. UK [9]Swiss Plasma Centre SPC, Lausanne, Switzerland [10] University of Sevilla, Sevilla, Spain

e-mail (speaker): mattia.siccinio@euro-fusion.org

The Edge Localised Modes (henceforth ELMs) are plasma instabilities associated with the formation of an edge transport barrier (so-called pressure pedestal) in H-mode tokamak operation. ELMs lead to a periodic release of particles and energy from the confined plasma region, mainly directed onto the divertor. In present experimental devices, the high confinement needed for DEMO is only readily achieved in the presence of type-I ELMs and sometimes of type-II and grassy ELMs. Extrapolations to large machines, as for example ITER and EU-DEMO [1], suggest however that even an actively cooled divertor could only withstand a very low number of unmitigated type-I ELM events before being severely damaged [2]. This occurrence is clearly incompatible with a long-term operation of the machine. Currently, many active methods for the mitigation, or even suppression of the type-I ELMs are under investigation in many laboratories. Still, the possibility of transferring such methods to a future, high power nuclear fusion reactor for the production of electricity is debatable. In view of the difficulties connected to, and the extremely challenging requirements on the active ELM mitigation or suppression, the decision has been taken for EU-DEMO to not consider any longer the ITER-like ELMy H-mode as a primary choice for the baseline plasma scenario [3]. Instead, the possibility of adopting other, naturally ELM-free plasma configurations shall be investigated. A plasma scenario which is naturally ELM-free, as for example the QH-mode [4], the I-mode [5], or even negative triangularity L-mode [6] would in fact be extremely beneficial for a machine like EU-DEMO, whose mission includes stringent availability requirements – to a much higher extent than ITER. With respect to ELMy H-mode, all ELM-free regimes exhibit however the obvious disadvantage of relying on a much more limited experimental database and on a weaker theoretical understanding, thus making their extrapolation towards reactor scales largely uncertain. In the course of 2019, two ad-hoc groups were established inside EUROfusion, with the purpose of reviewing the existing knowledge and proposing a research strategy for the next years for various ELM-free regimes (with focus on I-mode and QH-mode) as well as for Negative Triangularity – the latter being dealt with by a separate and dedicated ad-hoc group in view of the scarcity of devices able to host it and of the complete absence of devices optimized therefore. In the present work, the results of the two ad-hoc groups are presented, with special emphasis on the key knowledge gaps towards the qualification of the various regimes for an electricity producing DEMO reactor. These gaps are, for example, the difficulty of maintaining a sufficient poloidal flow shear for QH-mode, the potential impact on the fusion power due to the absence of density pedestal for I-mode and the MHD stability (ideal and resistive) for negative triangularity. The necessity of identifying from the very beginning all potential showstoppers associated to the employment of each plasma configuration in DEMO emerged clearly. In fact, it is of paramount importance to individuate and down select as early as possible the unsuitable solutions, and concentrate the (scientific and economic) effort on promising alternatives only, through a coordinated approach exploiting the features of the existing devices in EU and overseas, as well as via theory and modelling. Only thereafter, a demonstration and then a qualification of the scenarios shall take place, this possibly requiring the upgrade, or even the construction *ex novo*, of experimental facilities.

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