S9-2

European efforts for addressing long pulses and steady-state issues of magnetically confined plasmas

X. Litaudon[1], R. Albanese[2], M. Beurskens[3], S. Brezinsek[4], F. Castejon[5], S. Coda[6], A. Dinklage[7], A.J.H. Donné[8], T. Eich[7], G. Falchetto[9], G. Federici[8], J. Figueiredo[1], J. M. García Regaña[8,15], G. Giruzzi[9], J. Hobirk[7], L. Horton[10], S. Jachmich[11], E. Joffrin[9], D. Kalupin[8], K. Krieger[7], J. Lonnroth[1,16], P. Martin[11], M.L. Mayoral[8], H. Meyer[3], A. Murari[1], I. M. F. Nunes[13], DC. McDonald[8], C. Perez von Thun[1], H. Reimerdes[6], M. Romanelli[3], M. Rubel[14], E. Solano[1,5], G. Sips[10], M. Turnyanskiy[8], I. Voitsekhovitch[8], H. Weisen[6], F. R. Wenninger[8], S. Wiesen[4]

1) EUROfusion PMU, Culham Science Centre, Abingdon, Oxon, OX 14 3DB United Kingdom
2) CREATE-ENEA, Universita di Napoli, Naples, Italy
3) CCFE, Culham Science Centre, Abingdon, UK
4) Forschungszentrum Julich, Julich, Germany
5) The National Fusion Laboratory, CIEMAT, Madrid, Spain
6) Ecole Polytechnique Federale de Lausanne, CRPP, Lausanne, Switzerland
7) Max-Planck-Institut fur Plasmaphysik, Garching, Germany
8) EUROfusion PMU, Garching, Boltzmannstraße 2, D-85748, Garching, Germany
9) CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France
10) JET Exploitation Unit, Culham Science Centre, Abingdon, Oxon, OX 14 3DB United Kingdom
11) Laboratory for Plasma Physics, ERM/KMS, Brussels, Belgium
12) Consorzio RFX, Padova, Italy
13) Institute of Plasmas and Nuclear Fusion, Lisbon, Portugal
14) KTH Royal Institute of Technology, Stockholm, Sweden
15) Max-Planck-Insitut für Plasmaphysik, Greifswald, Germany
16) Aalto University, P.O. Box 14100, 00076 Aalto, Finland

e-mail of corresponding author: xavier.litaudon@euro-fusion.org

Pursuing the operation of magnetically confined fusion plasmas towards steady-state is one of the main challenging research areas in magnetic confinement fusion. Steady-state operation needs to integrate both physics and technological issues, on the route to a thermonuclear fusion power plant. With this long term perspective, Europe has elaborated a "Roadmap to the realisation of fusion energy" [1]. The European fusion roadmap sets out a pragmatic approach to achieve the goal of generating fusion electricity by 2050 with a demonstration fusion power plant (DEMO). The goal-oriented approach of the EU roadmap is set with eight different missions. The recent European progress and prospects for addressing issues related to plasma operation, heat exhaust and plasma wall interaction of the long pulse and steady-state magnetically confined plasmas are reviewed in this paper.

The first issue addresses the sustainment and the control of the magnetic configuration and kinetic profiles. Two lines of research are followed in Europe that rely on

i) the optimization of the tokamak configuration by a combination of self-generated bootstrap current complemented with non-inductive external current drive (Mission 1, 'Plasma regimes of operation'),
ii) the intrinsically steady-state magnetic configurations, with the stellarator (Mission 8, 'Stellarator').

Access conditions and confinement studies of high performance and high beta regimes are studied in JET and European Medium Size Tokamak experiments with metallic walls (Be/W ITER-like wall at JET and W wall in ASDEX-Upgrade). Recent confinement studies in metallic walls devices are reported [2] together with improved confinement regimes obtained at high beta [3]. In 2015, Wendelstein 7-X (W7-X) will start its first operation [4]. Its full scientific exploitation under steady-state conditions achieved beyond 2020 should provide the crucial milestones for the development of the helical-axis advanced stellarator (HELIAS) line. W7-X is equipped with superconducting coils and steady-state heating even in its first phase thus providing a versatile test-bed for steady-state developments.

The second issue concerns the development of heat-exhaust systems which must be capable of sustaining the transient and continuous large heat and particle fluxes of a future fusion power plant (Mission 2. Heat-exhaust systems). The baseline strategy for the accomplishment of Mission 2 consists of reducing the heat load on the divertor targets by radiating a sufficient amount of power from the plasma and by producing and controlling "detached" divertor conditions. Significant progress has been made on ASDEX-Upgrade where experiments have explored divertor operation at high P_{sep}/R=10MW/m (~2/3 of the ITER value) with a metallic environment [5]. The technology issues related to the development and tests of actively cooled plasma facing components (PFCs) that should handle continuous power fluxes in the range of ~10MW/m^2 are addressed in specific European linear plasma devices and in the upgrade Tore Supra tokamak, i.e. the WEST project. In addition, an aggressive programme to develop alternative divertor magnetic configuration (e.g. super-X, snowflake) is initiated in TCV [6] and MAST-U [7] and liquid metals PFCs for the divertor are also explored in e.g. FTU, ISTTOK and Magnum-PSI. The island and actively-cooled high-heat-flux divertor in W7-X comprehensively completes the asset of European exhaust studies particularly addressing 3D effects. The experimental and modelling effort should give technical and scientific inputs for an assessment of alternative divertor geometries and provide the required information for the decision on the parameters of a possible Divertor Tokamak Test.

Finally, on the route towards long pulse operation, one key issue is to develop, within the optimised divertor configuration, a PFC solution in a fully actively cooled environment ensuring a satisfactory control of the density, lifetime of the components, material erosion/co-deposition, tritium wall inventory and dust production. Europe contributes significantly on this issue by operating and testing full metallic PFC solutions in ASDEX-Upgrade and JET. Significant reduction of deuterium retention and dust production are reported with metallic walls compared to C walls [8, 9]. In 2016, WEST with an actively cooled W divertor will also contribute actively to these plasma wall interaction aspects in long pulse conditions.

To conclude, the experimental activity is supported by a coherent and integrated research programme addressing code development, diagnostics and hardware enhancements as well as theory with first principle modelling (validation on experiments), stellarator optimization and modelling, integrated modelling for the preparation, analysis of the experiments, and finally, the extrapolation towards JT-60SA, ITER and reactor conditions including the modelling of alternative power exhaust solutions for DEMO.

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