Preparation of exploitation of medium-size tokamaks under European roadmap for the realization of fusion energy.

M. Turnyanskiy[1,2], M. Beurskens[3], A. Burckart[4], S. Coda[5], M. Cecconello[6], K. Crombe[7], M. Komm[8], T. Donne[1,9], T. Eich[4], B. Esposito[10], F. Felici[11], M. Garsia-Munoz[12], A. Hakola[13], X. Litaudon[1,14], P. Martin[15], M-L. Mayoral[1,2], D.C. McDonald[1,2], J. Mlynar[8], H. Meyer[2], R. Neu[4], P. Piovisan[15], H. Reimerdes[5], F. Romanelli[10], R. Scannell[2], O. Tudisco[10]

[1]*EUROfusion PMU, Garching, Boltzmannstraße 2, D-85748, Garching, Germany*
[2]*CCFE, Culham Science Centre, Oxfordshire OX14 3DB, United Kingdom*
[3]*Max-Planck-Institut for Plasma Physics, Wendelsteinstr. 1, 17489 Greifswald, Germany*
[4]*Max-Planck-Institut für Plasmapysik, Boltzmannstraße 2, D-85748, Garching, Germany*
[5]*EPFL, CRPP, CH-1015 Lausanne, Switzerland*
[6]*EURATOM-VR Association, Department of Physics and Astronomy, Uppsala University*
[7]*Laboratory of Plasma Physics, ERM/KMS, Association Belgian State, Brussels, Belgium*
[8]*Institute of Plasma Physics AS CR, Za Slovankou 3, 18200 Prague 8, CZ*
[9]*EURATOM-FOM, PO Box 1207, 3430 BE Nieuwegein, The Netherlands*
[10]*Associazione EURATOM-ENEA sulla Fusione, CR Frascati, Roma, Italy*
[11]*University of Technology, PO Box 513, 5600MB, Eindhoven, The Netherlands.*
[12]*FAMN Department, Faculty of Physics, University of Seville, 41012 Seville, Spain*
[13]*VTT, Association Euratom-Tekes, PO Box 1000, FI-02044 VTT, Finland*
[14]*CEA, IRFM, F-13108 Saint-Paul-lez-Durance, France*
[15]*Consozio RFX, Corso Stati Uniti 4, I-35100, Padova, Italy*

To implement the European fusion research programme, outlined in the "Roadmap to the realisation of fusion energy" and published in 2012 [1], a coordinated programme of upgrades to the European Medium-Size Tokamaks (MST) (AUG, MAST-U, TCV) has been identified. A focus is to enable the integrated exploitation of the MST and JET devices, both through the selection of diagnostics and the staging of the upgrades in time. This paper discussed the scientific case made to identify the upgrades and their implementation on the three MST devices.

Scientific case for upgrades

The European Medium-Size Tokamaks support JET in preparing the physics basis for plasma operation (Mission 1) and heat-exhaust systems (Mission 2) on ITER and DEMO. For each of these two missions, the long-term physics goals of the MST campaigns and the gaps in the existing diagnostic sets that put the achievement of these goals at risk have been determined. A series of pre-conceptual designs and assessments have selected a set of MST enhancement projects that best reduce the risk within the available technical capabilities and resources available.

The area of plasma operation (Mission 1) provides a physics basis for integrated ITER scenarios which can be extrapolated to DEMO. Four priority areas have been identified in the gap analysis: avoidance and mitigation of disruption and Runaways Electrons (RE); control of core contamination and dilution from W PFCs; optimisation of the fast ion confinement and current drive and developing of integrated scenarios with controllers. Each MST has an important contribution to make in solving this mission challenges. This requires a targeting approach for development and enhancement of the plasma diagnostics on MSTs in order to fully enable the research programme in those priority areas and bring it to the standard expected from the common EUROfusion facility.

The challenges of the second area of heat exhaust (Mission 2) remain the main obstacle towards the realisation of magnetic confinement fusion. The strategy to achieve the challenges and goals of this mission can be broadly separated in two main approaches: baseline strategy of detachment control for the ITER and DEMO and investigations of alternative power exhaust solutions for DEMO. The latter acts as a risk mitigation as significant risks remains that the high performance plasma is incompatible with the larger core radiation fraction required in the DEMO [2]. ASDEX Upgrade with its all tungsten PFCs and high P_{sep}/R plays an important role as a medium-sized counterpart to JET in studies for the baseline heat exhaust solution specifically for experimental investigations which rely on all-metal PFCs. TCV and MAST-U are undergoing major upgrades, which allowing proof of principle investigations on snowflake and Super-X divertor configurations. Both conventional and advanced divertor approaches require improvements in advanced diagnosis as a part of research strategy.

Design and construction of diagnostics

The experimental investigations on both JET and the MSTs are the focus of the European programme to achieve main goals of these missions. A special, multi project Work Package has been established by the EUROfusion consortium in preparation for solving associated challenges on MST. The project selection and priority are based on the fusion roadmap [1] recommendations as well as the MST timeline and programmatic needs. For example, during the period 2014-18, a series of experimental campaigns and shutdowns are planned in the European divertor tokamaks. Planning ahead and providing the necessary diagnostic tools for

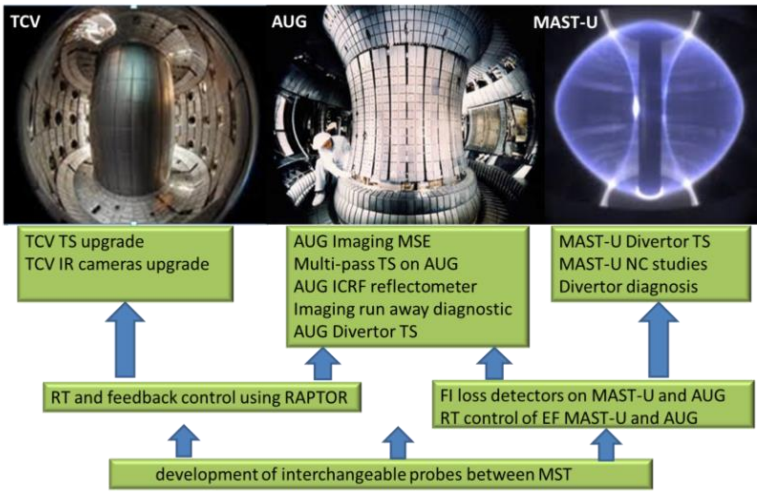

Figure 1. The activities comprised as the result of the gap analysis of the MST programmatic and scientific demand.

timely implementation of the EUROfusion physics programme on MSTs is one of the main aims of this work.

The ongoing diagnostic enhancements comprised as the result of the gap analysis of the MST programmatic and scientific demand are shown in Fig .1. The MST contributions are particularly valuable for the risk mitigation strategies for the Fusion Power Plant heat-exhaust systems such as investigation of alternative power exhaust solutions by exploiting innovative divertor configurations resulting in MST wide EUROfusion investment in edge and divertor diagnosis projects. They include development of the modern, high resolution divertor Thomson Scattering (TS) systems on MAST-U and AUG, upgrades for the edge TCV TS and IR imaging systems [3] and supported by further MST wide diverter probe development [4].

ITER will play the ultimate role in proving the applicability of the "conventional" power exhaust as well as plasma control and heating scenarios for DEMO. The numerous questions still remain outstanding and require further input from the ongoing physics programme on the existing fusion facilities. The related gap analysis of the MST programme has identified the desirable MST enhancement projects to address these challenges particular in the selected priority areas of the real time diagnosis of disruptions, conditions and control of runaway electron generation, improving and developing of ITER relevant fast ions diagnostics as well study of the physics of sheath effects both in tokamak and controlled environment of the test stands (see Fig 1.).

These efforts are further supported by the investigations which are better performed on the test stands and smaller European machines, outside of MST umbrella (e.g. COMPASS, FTU etc.), for safety, simplicity or monetary reasons. Testing the physics and diagnostic ideas on the smaller devices, particularly in case of high safety concerns like runaway or disruptions studies is one of the ongoing contributions in this area. For example the recent successful measurements of the synchrotron radiation spectra from the runaway electrons on AUG using imaging RE diagnostic system have greatly benefited from the previous proof of principle project tests and experience performed on FTU runaway experiments [5].

The physics of sheath effects in controlled and simplified environment of the test stands (IShtar facility [6]) where innovative ideas can be better tested and diagnosed is another example of such contribution. The described efforts are a collaborative work of 17 European research units with involvement of all three MSTs. Several of selected activities share their experience and contribute to more than one MST physics programme. In some cases, like development of the ITER relevant fast ion loss detectors, the synergy of the diagnostic development under common project umbrella is providing direct benefits and contributions to a possible solution on the JT60SA and ITER diagnostic challenges. Shortage of the adequate ITER applicable diagnostic technique for the fast ion and alpha particles combined with an importance of the fast ion and current drive physics in the JT-60SA research plan makes these contributions particular valuable.

After the initial setup and implementation of the EUROfusion consortium strategy on MST enhancement a number of the projects are now coming to the successful completion. Those diagnostics enhancements are producing their first results, contributing to the physics programme on the MSTs and paving the way for the future projects to address the arising needs and challenges of the European fusion programme.

Acknowledgments

This work has been carried out within the framework of the EUROfusion Consortium and has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement number 633053. The views and opinions expressed herein do not necessarily reflect those of the European Commission.

[1] F. Romanelli et al., Fusion Electricity - A roadmap to the realisation of fusion energy, European Fusion Development Agreement (EFDA) 2012, ISBN 978-3-00-040720-8

[2] M. Turnyanskiy et al, Fusion Engineering and Design 96–97 (2015) 361–364

[3] R. Maurizio et al., Infrared measurements of the heat flux spreading under variable divertor geometries in TCV, P4.027 this conference

[4] B.S. Schneider et al., Proceedings of Science, in print. Also see P5.055 this conference.

[4] F. Causa, Imaging and spectroscopy of synchrotron emission from runaway electrons in FTU, P5.017 this conference

[5] K. Crombe et al., Characterization of the RF plasma on IShTAR, O5.129 this conference