Diagnostic developments for WEST

C. Fenzi[a,]*, J. Bucalossi[a], C. Bourdelle[a], Y. Corre[a], X. Courtois[a], D. Douai[a], A. Ekedahl[a], D. Elbeze[a], N. Fedorczak[a], C. Grisolia[a], C. Gil[a], R. Guirlet[a], J. Gunn[a], P. Hennequin[b], P. Lotte[a], L. Manenc[a], Y. Marandet[c], D. Mazon[a], O. Meyer[a], M. Missirlian[a], P. Moreau[a], E. Nardon[a], B. Pégourié[a], R. Sabot[a], S. Salasca[a], J.M. Travere[a], E. Tsitrone[a] and the Tore Supra team

[a] *CEA, IRFM, F-13108 Saint-Paul-Lez-Durance, France.*

[b] *Ecole Polytechnique, LPP, CNRS UMR 7648,91128 Palaiseau, France.*

[c] *Aix-Marseille Université, CNRS, PIIM, UMR 7345, Marseille F-13397, France.*

INTRODUCTION

The WEST project (Tungsten (W) Environment in Steady State Tokamak, is targeted at minimizing risks in support of the ITER divertor strategy, bringing together for the first time tungsten actively cooled component technology and tokamak environment [1]. It consists of implementing an actively cooled tungsten divertor, representative of ITER divertor technology, into the long pulse tokamak Tore Supra, taking advantage of its unique capability for active cooling and steady state heating. The new X-point configuration will allow H-mode regimes, hence providing relevant plasma conditions for validating plasma facing component (PFC) technology and assessing high fluence plasma wall interactions with tungsten. Besides this main focus, WEST will also open new experimental opportunities for developing integrated long pulse H mode operation and exploring reactor relevant regimes in a metallic environment. The power handling capability of the W monoblocks will be tested in an integrated tokamak environment from 2016 when the first ITER representative PFC will be implemented in Tore Supra. The final WEST full actively cooled divertor configuration, expected to be available in 2018, will complement existing W divertor experiments in Europe (e.g. JET and ASDEX-Upgrade) by adding the important component of long pulse capability and actively cooled surfaces to the operational experience being gathered elsewhere. Extended plasma exposure provides access to ITER-critical issues such as PFC lifetime (melting, cracking etc.), tokamak operation on damaged metallic surfaces, real time heat flux control through PFC monitoring, fuel retention and dust production etc. This brings new challenges in terms of measurement capabilities for Tore Supra, to fulfill WEST program requirements. WEST will provide a platform for developing advanced control tools (e.g. wall monitoring system for PFC protection and accurate heat load control in a metallic environment, control of tungsten contamination over long pulses, etc…), as well as technical diagnostic developments and tests. This paper gives a global overview of the diagnostic systems foreseen for WEST, and focuses on new and challenging diagnostics proposed.

KEY BASELINE DIAGNOSTICS

Tore Supra is presently equipped with an extensive set of diagnostics located mainly in equatorial and vertical ports [1]. The transformation from the current circular limiter geometry of Tore Supra to the required X-point configuration is achieved by installing a set of water cooled copper poloidal coils inside the lower and upper parts of the vacuum vessel (Figure 1). If the addition of the lower divertor has a limited impact on existing diagnostics, the presence of the upper divertor and its supporting structures induces a challenging reduction of the available space inside the upper ports and at the upper port flanges. Some key diagnostics, which are compulsory for tokamak control and operation, are significantly impacted (detailed information on diagnostic integration challenges and major modifications can be found in [2]), such as the IR thermography system (a new comprehensive IR system for machine protection and measurements in a metallic environment is being developed), the interferometry-polarimetry system (new channels have been defined in order to guarantee accurate electron density profile and current density profile reconstructions), the magnetic measurements (up to 460 sensors, some of them being ITER-like magnetic sensors, are foreseen for plasma equilibrium and plasma diamagnetism, low and high frequency MHD activities, eddy and halo current measurements),

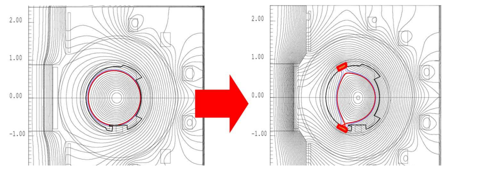

Figure 1: *Tore Supra magnetic configuration modification. Left: current circular geometry. Right: WEST X-point geometry, with upper and lower divertors.*

Ports	Equatorial ports		Vertical ports
Q1A	Inspection Arm UV spectroscopy **Visible camera**	Doppler reflectometry Thomson scat. /**HRTS** **Fast visible camera**	Thomson scattering dump
Q1B	ICRH antenna		IR lower divertor
Q2A	Bolometers UV spectroscopy **Visible camera**	ECE **IR upper divertor** Soft X-Rays or **GEMs**	Bolometer or Soft X-Ray / **GEM**
Q2B	ICRH antenna		IR lower divertor
Q3A	Interferometry-polarimetry	Langmuir probes Profile reflectometry	Langmuir probe or **LIBS** / TBC
Q3B	ECRH antenna		IR lower divertor
Q4A	ICRH antenna		Langmuir probe or **visible spectro**
Q4B	Hard X-Ray UV spectroscopy Visible camera	Impurity injection Fast visible camera Bremsstrahlung	IR lower divertor
Q5A	X-ray spectro. (**XICS**) *Pellet injection*	**Bolometer** TBC	*Pellet injection* Pellet camera **Bolometer** TBC
Q5B	Visible camera Fluct. reflecto.	*Supersonic gas injection*	IR lower divertor
Q6A	LHCD antenna		Disruption mitigation valve
Q6B	LHCD antenna		IR lower divertor

Table 1*: Summary of main diagnostic implementation [3]. New diagnostics are indicated in bold. Remaining uncertainties on diagnostic location is marked as to be confirmed (TBC). Non diagnostic systems (as fuelling systems) are indicated in italic.*

or the calorimetry system which is being fully redesigned for machine protection and energy / power balance evaluation. Those diagnostics are part of the baseline set required for WEST, including as well new key diagnostics as an extended visible spectroscopy diagnostic for extensive coverage of potential W source and W influx characterization with up to 208 lines of sight, new Langmuir probes based on the design foreseen for ITER for divertor target monitoring together with new probes for an extensive radial and poloidal SOL coverage, or divertor embedded thermocouples. The baseline set also includes existing diagnostics with minor adaptation, as V-UV spectroscopy, ECE, soft X-rays, reflectometry (density profiles, density fluctuations), Doppler reflectometry, hard X-ray, visible Bremsstrahlung, bolometry, barometry, mass spectrometer, visible cameras, neutron diagnostic, etc. A synthetic view of undergoing main diagnostic implementation is illustrated in Table 1, port locations being illustrated in Figure 2.

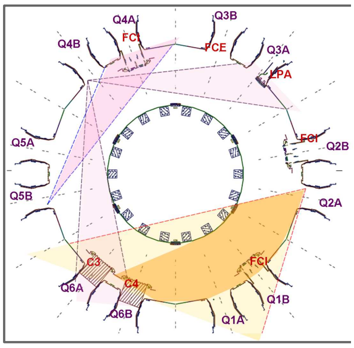

Figure 2: *Current Tore Supra port locations. Undergoing evaluation of possible equatorial IR thermography views are also illustrated.*

UNDERGOING DEVELOPMENTS AND NEEDS

Beyond the baseline diagnostic set foreseen for WEST described above, additional systems are being considered to reinforce and expand the scientific output of WEST. Most of those additional systems are foreseen to be developed within the frame of collaboration opportunities for the WEST platform exploitation (note that collaborations for baseline diagnostics are also foreseen). Even if not available for the first plasma operation phases, the possibility of their integration in a further stage will be assessed. The main systems currently under consideration are micro-bolometers for improved divertor radiative power monitoring, high resolution / edge Thomson scattering (HRTS) for pedestal characterization, X-ray imaging spectroscopy (IXCS) for ion temperature, ion density and plasma rotation velocity measurements, He beam spectroscopy for plasma edge temperature measurements, neutral particle analyzers (thermal, fast) for isotopic ratio and fast ion distribution evaluation, imaging ECE (IECE) system for impurity transport and MHD studies, improved soft X-ray system with Gas Electron Multiplier (GEM) detectors for impurity transport and MHD studies, burn out acoustic probes for critical heat flux detection,

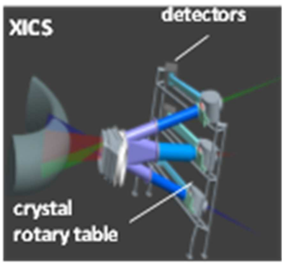

Figure 3: *possible IXCS diagnostic configuration for WEST (3 viewing lines).*

laser induced breakdown spectroscopy for retention studies, Speckle interferometry for erosion studies, and dust production / collection systems. Hereafter are given some details regarding possible developments for the IXCS, HRTS and bolometry systems. An IXCS diagnostic with ITER-relevant features (design principles similar to the ITER edge spectrometer, use of advanced property solid state detectors) is being considered. The proposal could consist of a multiple branch system (Figure 3), aiming at providing a full plasma cross-section view hence addressing emissivity function asymmetry issues and allowing for poloidal rotation measurements as well. Provided the range of expected WEST plasma parameters (T_e up to 7keV, n_e up to 9×10^{19} m^{-3}), the system will have to be designed for use with He-*like* and H-*like* Argon, as well as He-*like* Iron (more impurity monitoring could be possible). Moreover, new branch of hybrid pixel detector, with double energy thresholds / counters per pixel, will be highly valuable for such a system. Another key measurement need concerns (n_e, T_e) pedestal characterization, which could be achieved using HRTS technique. As an alternative, possible edge spatial resolution improvement methods are being explored for the present Thomson scattering system (Figure 4). This would allow limited impact on the existing diagnostic configuration, but open questions related to signal to noise ratio and light reflection impact issues are being investigated. Finally, one could also mention bolometry developments for spatially resolved radiative power. As mentioned above, the available space inside the upper ports and at the upper port flanges is reduced. This significantly impacts the bolometry spatial coverage (see high field side and divertor region coverage, Figure 5), and degrades the diagnostic performance in terms of tomography. One possible solution could involve micro-bolometers, which could allow for recovering tomography capability.

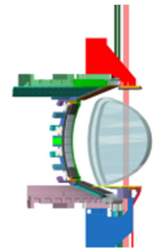

Figure 4: *Current Thomson scattering laser line path in WEST.*

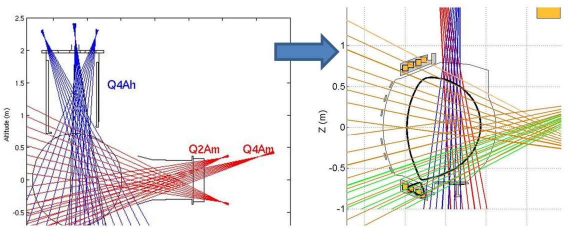

Figure 5: *Bolometry configuration in Tore Supra (left) and current status in WEST configuration (right) with clear impact on spatial coverage.*

For more information on WEST and collaboration opportunities, visit our website *http://www-dsm.cea.fr/fr/Vie-scientifique/Dossiers/The-WEST-Itinerary-for-Iter*.

References: [1] J. Bucalossi *et al.* Fusion Engineering and Design **86** (2011) 684–688, [2] C. Gil *et al.* Fusion Sci. Technol. **56** (2009) 1219, [3] S. Salasca *et al.* presented at the 25th SOFE conference, San Francisco, 2013.

*corresponding author: christel.fenzi@cea.fr