Confinement properties in the large aspect ratio, full tungsten environment of the WEST tokamak

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INTRODUCTION

WEST is a metallic tokamak operating in L mode since December 2016. Its specificities are an aspect ratio value of 5-6 and the inner wall covered with tungsten tiles plus ITER like PFU on lower divertor. Its plasmas are dominantly electron heated (ICRH and LHCD) and torque free (no NBI). [1] [Bucalossi et al submitted to NF 2021]

In this work, we analyze extensively the database of WEST plasmas to characterize the operational domain, based on plateaus of quasi-steady phases of power and current.

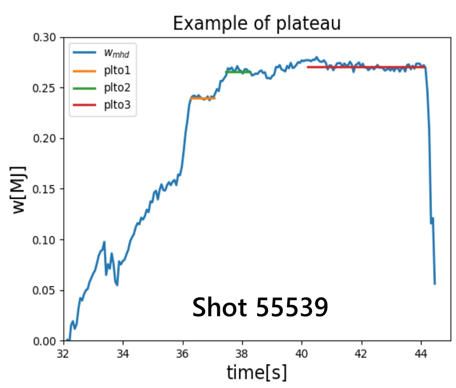
In WEST database, 20% of the detected plateaus are affected by a rapid collapse of the central electron temperature or do not reach more than 1.5 keV at the core. Since reaching plasmas with enhanced stability is fundamental to obtain high tokamak performances, the core radiative collapse is modelled using RAPTOR to understand the causality leading to colder plasma core. [2][3]

WEST database based on plateau phases

The performed studies take into account statistics calculated on plateaus of total power intersecting plasma current plateaus (quasi-steady states). Different diagnostic measurements are time averaged on each plateaus and added to the database.

The plasma energy content computed from polarimetry constrained equilibrium reconstructions is chosen for the analysis. [Faugeras Fusion Engineering and Design 2020]

$$\tau_{mhd} = \frac{W_{mhd}}{P_{tot} - \frac{dW}{dt}} = \frac{\frac{3}{2}\int_V P\,dV}{P_{ohmic} + P_{aux} - \frac{dW}{dt}}$$



The WEST database contains more than 1000 entries:

- L-mode pulses (P_{aux}>0.5MW);
- deuterium only pulses;
- heated by lower hybrid and ion; cyclotron resonance heating;
- Lower single null configuration.

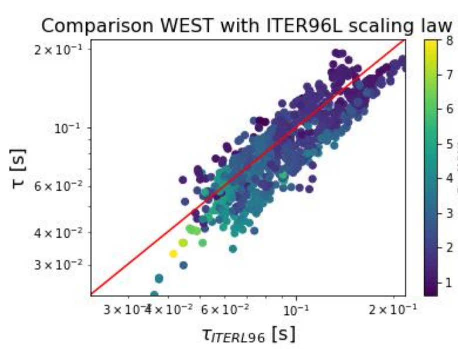
The parametric dependence of the confinement time with respect to the aspect ratio

The engineering parameters scaling law for the energy confinement time

$$\tau = C\, Ip^{\alpha_P} B^{\alpha_B} P_{tot}^{\alpha_P} n_e^{\alpha_{ne}} M^{\alpha_M} R^{\alpha_R} \varepsilon^{\alpha_\varepsilon} k^{\alpha_k}$$

is applied on WEST database accounting only plasma current, the line averaged electron density and the total power.

	α_{Ip}	$\alpha_{ne_{bar}}$	$\alpha_{P_{tot}}$	RMSE
$\tau_{ITER96L}$	0.96	0.40	-0.73	18.9
τ_{WEST}	1.28	-0.19	-0.72	13



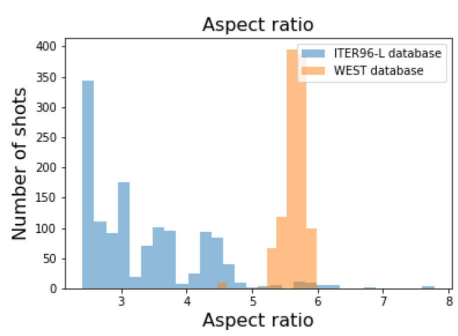
A weaker dependence on density is found. But WEST confinement time is well aligned with ITER96-L

WEST data are added to the existing ITER96L database with machines having aspect ratio (A) ranging from 2.41 to 7.78, but with few shots in the range 5-6 [4].

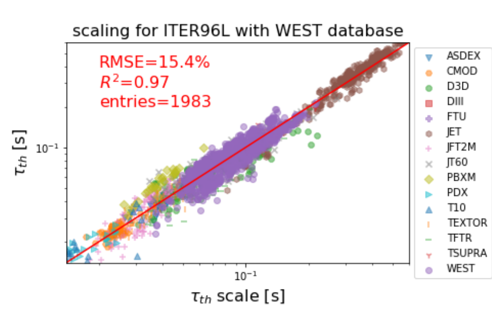
The engineering coefficients are combined through the Kadomtsev transformation to compute the dimensionless scaling law. [Y.Sarazin, NF, 2020]

$$\Omega_i \tau = \rho_*^{x_{\rho_*}} \beta^{x_\beta} \nu_*^{x_{\nu_*}} q^{x_q} M^{x_M} \varepsilon^{x_\varepsilon} B^{x_B} k^{x_k}$$

[Luce, PPCF, 2008]



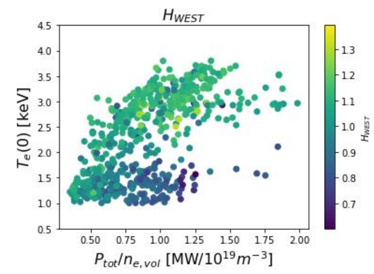
Variable	ITER96-L	ITER96+WEST
q	-3.74	-3.88
B_T	0	0
k	3.22	3.26
R/a	0.04	0
M_{eff}	0.67	0.67
ρ_*	-1.85	-1.91
ν_*	0.19	0.18
β	-1.41	-1.45
Entries	1313	2400
WEST entries	-	1087
RMSE	15.8%	16.3%



The aspect ratio does not play an important role in the scaling. Even if WEST has an aspect ratio larger than the other tokamaks in ITER96L database, the regression coefficient still close to zero.

Core radiative collapse modelling with RAPTOR

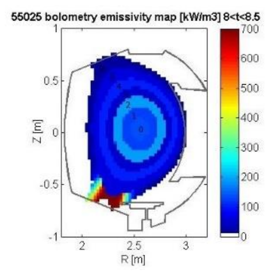
Two different confinement states coexist in the WEST L-mode operation. The hot branch, is characterized by a high central electron temperature, internal inductance and neutron flux and a low tungsten peaking.

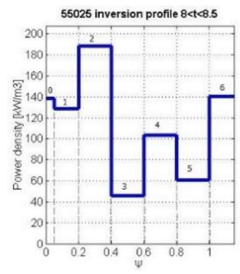


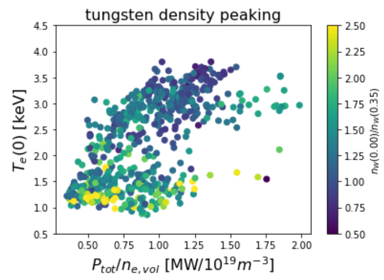
Thanks to the bolometry tomography it is possible to compute the power emission density profile.

Above 1keV all the radiated power is due to tungsten emission.

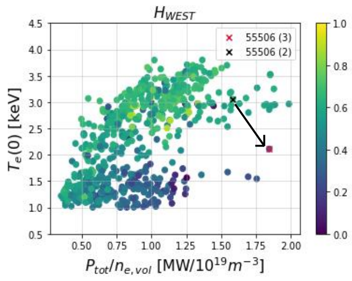
$$n_W \approx \frac{P_{rad,W}\,[W/m^3]}{n_e L_W(T_e)} \qquad W_{peak} = \frac{n_{W(0.0)}}{n_{W(0.35)}}$$

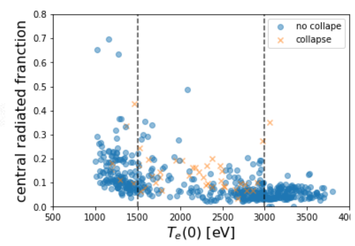


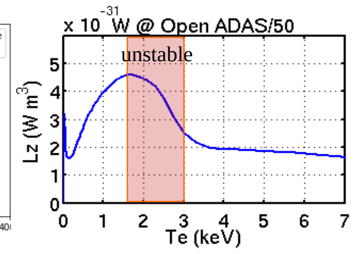




In WEST L-mode database 20% of the detected plateaus are affected by a rapid collapse of the central electron temperature or do not reach more than 1.5 keV .



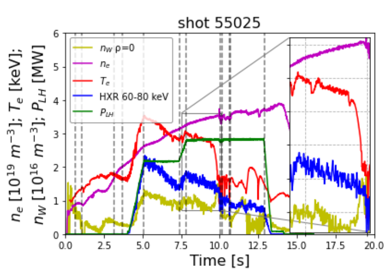


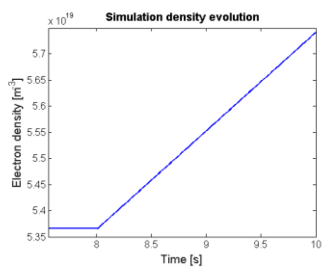


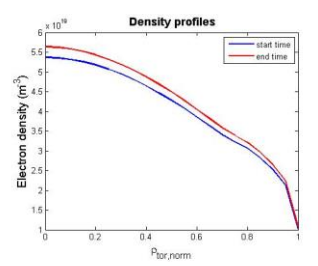
The 1D transport code RAPTOR is used to model the collapse.

T_e	T_i	n_e	n_w	P_{rad}	Heat transport	Current diffusion
BgB	reconstructed with METIS	fixed, by interferometry inversion and reflectometry	Computed to match P_{rad}	ADAS 50	predictive	predictive

[Puetterich PPCF 2008]

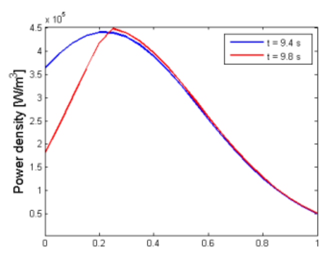






The density rises leading to slight $T_e(0)$ drop. The acceleration of the $T_e(0)$ drop is concomitant with an increase of the core W peaking.

At first a flat W profile is found to reproduce well the measured P_{rad}, then, a peaked core W profile is assumed to reproduce the core bolometer chords increase.

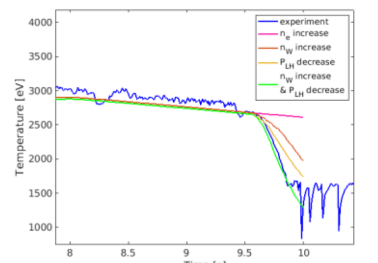


The increase of the tungsten in the center of the plasma is not sufficient to reproduce the collapse.

The central value of the LHCD power deposition is reduced in an ad-hoc manner.

This reduction follows the trend observed in the central emissivity profile reconstruction from the hard X rays 60-80 keV camera.

With both conditions the speed of the collapse is reproduced.



CONCLUSION

- WEST L mode energy content agrees with ITER96L scaling predictions;
- The scaling coefficients do not change significantly adding WEST shots directly to ITER96L confirming the weak aspect ratio dependence reported in the ITER96L;
- Two different confinement states coexist in the WEST operation: one with Te(0)>3keV and one with Te(0) <1.5 keV at the same power/<n>;
- The core T_e rapid collapse from 3 to 1.5 keV cannot be explain solely by an increase of the density. An increase of the core W peaking as well as an off-axis shift of the LHCD power deposition are necessary to reproduce the observed T_e(0) collpase.

References [1] http://west.cea.fr/WESTteam.
[2] F. Felici et al, Nucl. Fusion, 51(8):083052, aug 2011.
[3] K. L. van de Plassche et al, Physics of Plasmas, 27(2):022310, 2020.
[4] S.M. Kaye and ITER Confinement Database working Group 1997 Nucl. Fusion 37 1657