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Status of scenario studies for WEST

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24 October 2012

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Introduction: what is WEST ?

- Objective: test ITER key in-vessel component technology prior its installation on ITER: tungsten monoblock divertor
  - Test in most realistic conditions the technology foreseen for ITER: ELMs cycles over long durations

- Means:
  - Adapt Tore Supra to X-point configuration
  - Replace present Carbon limiter by Tungsten divertor

- Advantage: Tore Supra is already equipped with stead-state technologies, so the investment is relatively moderate (~ 20 million euros for the Tore Supra adaptation)
  - Supra-conducting TF coils
  - LHCD to provide long pulses
  - Active cooling of the PFC

Status of WEST scenario studies

- WEST shall demonstrate long pulse divertor operation with large number of ELM cycles under stationary conditions
  - Access to H-mode and pedestal characteristics
  - ***Operational window*** and development of ***~ 1 minute long, robust scenarios***

- As a by-product, investigation of advanced ***non-inductive scenarios with far off-axis LH current drive***

- Up to now, the scenario studies have been relatively basic and not extensive, the core of the WEST project focuses on a technological objective
  - What you will see today was essentially supporting the feasability phase of the project (2010 – 2011)
  - Now the WEST project is started and needs deeper preparation via Integrated Modelling

Access to H-mode

- ***Easy accessibility to H-mode at B_T=3.85T (even at high density ne/nGR~0.9) and B_T=2T with 6MW LHCD, 9MW ICRH.***

L/H transition threshold:

$P_{L/H} = 0.042\ n_{20}^{0.73}\ B_t^{0.74}\ S^{0.98}$ (MW) (1)

$P_{L/H} = 0.072\ n_{20}^{0.7}\ B_t^{0.7}\ S^{0.9}\ (Z_{eff}/2)^{0.7}\ F(A)^{0.5}$, (2)

$F(A) = 0.1A/f(A)$, $f(A) = 1\text{-}[2/(1+A)]^{0.5}$

["Progress in ITER Physics basis", Nuclear Fusion 47 (2007)]

$P_{L/H} = 0.0488\ e^{\pm 0.057}\ n_{e20}^{0.717\pm0.035}\ B_T^{0.803\pm0.032}\ S^{0.941\pm0.019}$ (3)

$P_{L/H} = 2.15\ e^{\pm 0.107}\ n_{e20}^{0.782\pm0.037}\ B_T^{0.772\pm0.031}\ a^{0.975\pm0.08}\ R^{0.999\pm0.101}$ (4)

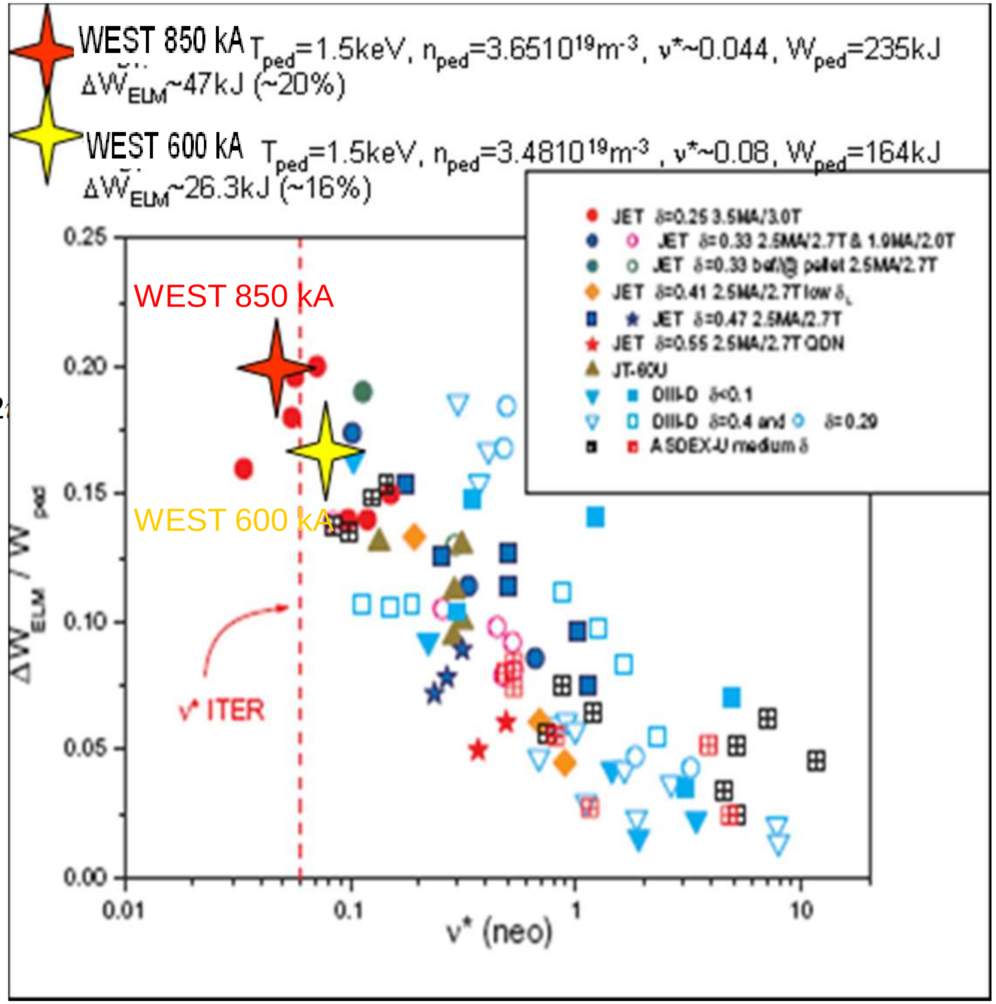
[Y R Martin 11th IAEA TM on H-mode J.of Physics 123 (2008)]

B_t (T)	n_e ($10^{19}m^{-3}$) (n_e/n_{GW})	(1)	(2)	(3)	(4)
		$P_{L/H}$(MW)			
3.85	4 (0.45)	3.3	4.2	3.6	4
3.85	8 (0.9)	5.4	6.8	5.9	6.8
2	2 (0.45)	1.2	1.6	1.3	1.4
2	4 (0.9)	2	2.7	2.1	2.4

WEST pedestal will operate at ITER collisionality

Type I ELM size ΔW_{ELM} ~47 kJ (ν^*~0.044).

V_{pl}=13.4-11.5m^{-3}, T_{ped}=1.5keV, n_{ped}=3.65-3.48$10^{19}m^{-3}$, q_{95}=2.95-4, R=2.53-2.58m



$\tau_d \sim 2$

Large proportion of ΔW_{ELM} arrives after $\tau_{//ion}$ (JET,AUG).

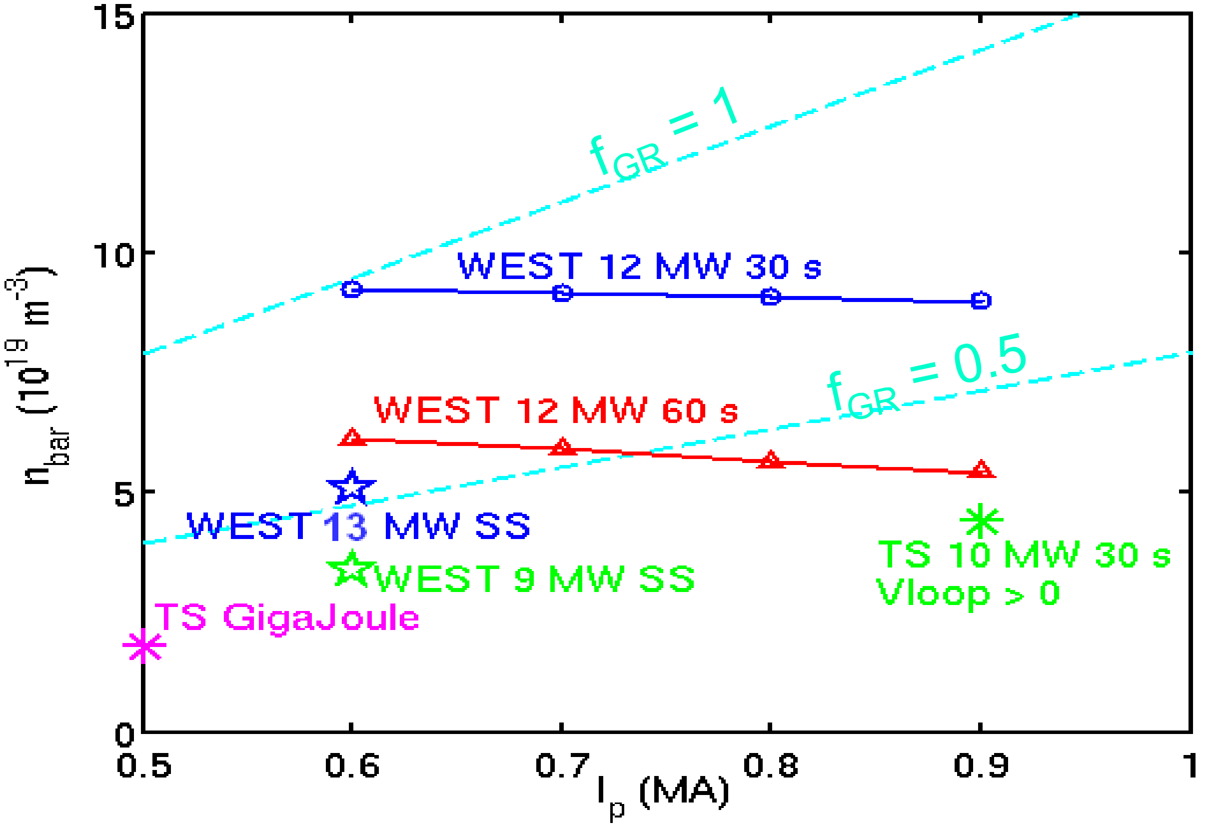
Deposition time for TSDT:

$$\tau_d \sim 2\tau_{||} \sim 0.4ms$$

In/out asymmetry: 2:1 energy to inner divertor:
~31.3kJ and ~15.7kJ to outer for ΔW_{ELM} ~47 kJ (ν^*~0.044).

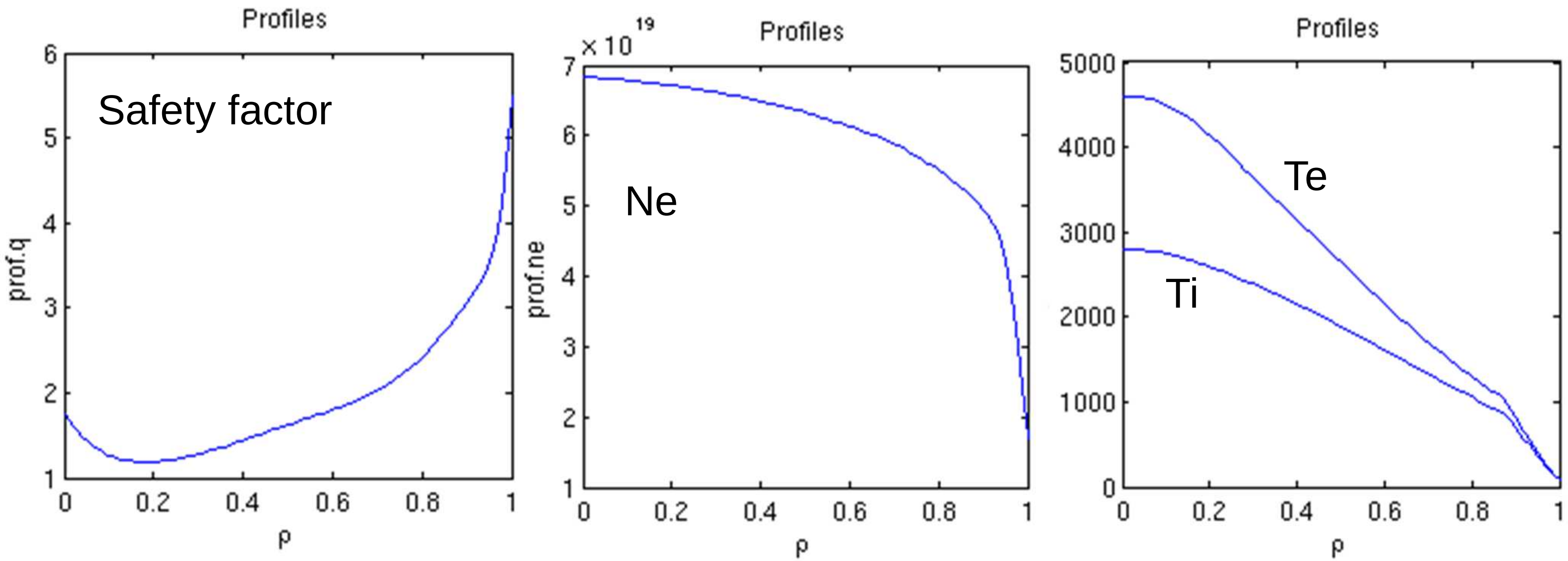
Operational window for long pulses

- ***Routine operation of 30 s actively cooled Tungsten divertor at high Greenwald fraction***, with 6 MW ICRH + 6 MW LHCD
- Conservative assumptions : $H_{98} = 1$, η_{LHCD} value from low Ip, low Te fully non-inductive L-mode plasmas (METIS hybrid 0D/1D modelling)
- In addition : fully steady-state operation at Ip = 600 kA, $f_{Gr} = 0.35$, 9 MW



Nominal scenario for long pulses

- CRONOS simulation
- Ip = 600 kA, of which I_{LHCD} = 260 kA (43 %), $I_{Non\text{-}Inductive}$ = 430 kA (71 %)
- Nbar = 6.10^{19} m^{-3}, prescribed profile
- P_{ICRH} = 6 MW, P_{LHCD} = 3 MW (C3PO/LUKE obtains η_{LH} = 1.25 10^{19} $A/W/m^2$)
- Plateau duration: 138 s for 7 Wb assumed in the plateau
- Fixed pedestal height, core transport normalized to H_{98} = 1
- Stationary profiles:



More scenario studies …

- 4 scenarios simulated with CRONOS (2 values of Ip x 2 values of density)
- Conservative assumptions on energy confinement: H_{98} = 1 by adjusting Tped, Bohm/gyro-Bohm model predicts Te, Ti in plasma core – potential ITBs not modeled
- 9 MW ICRH, up to 6 MW of LHCD power (C3PO/LUKE)
- The first three scenarios feature far off-axis LHCD deposition (r = 0.6 - 0.8) but the q-profile reversal is only local and transient. NB pessimistic « no ITB » assumption
- Scenario 4 is quite interesting since features mid-radius LH deposition and steady-state q-profile reversal at 100 % non-inductive current drive

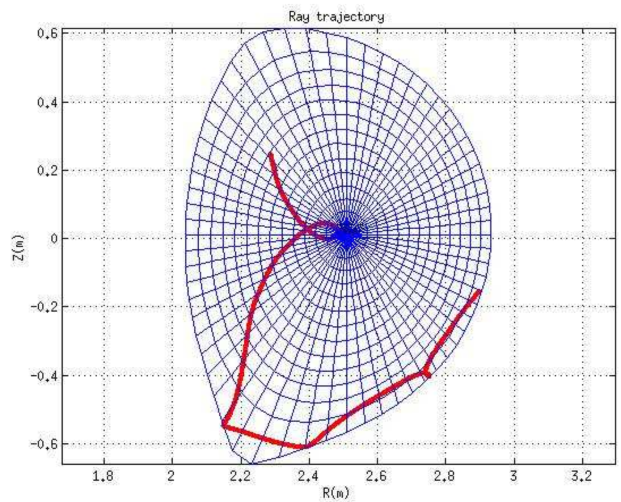
Scenario	Ip (kA)	f_G	q_{95}	f_{NI}	$f_{bootstrap}$	ρ_{LHdep}	T_{ped}(keV)	H_{98}
1	850	0.55	2.95	0.7	0.35	0.65	1.3	0.95
2	850	0.40	2.95	0.9	0.3	0.8	1.6	0.96
3	600	0.75	4.05	0.66	0.4	0.65	0.9	1.0
4	600	0.55	4.05	1	0.4	0.55	1.2	1.0

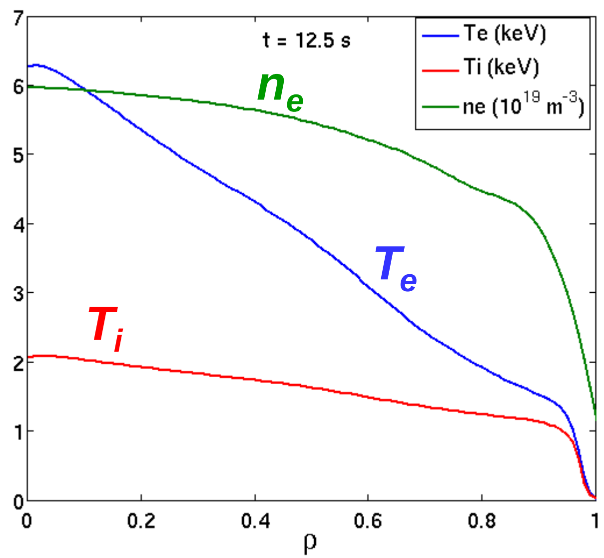
Steady-state scenario

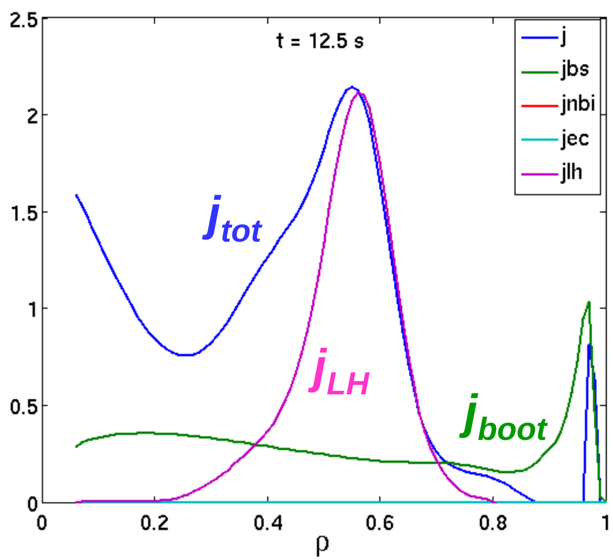
q-profile and LH deposition as in ITER SS scenario

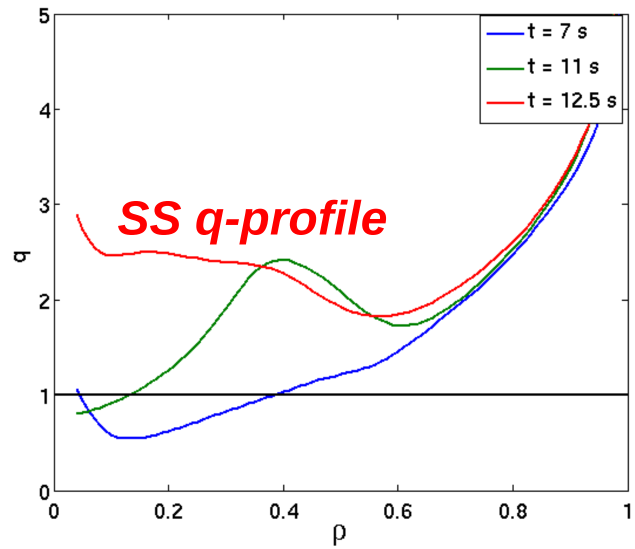
- *LHCD @ mid-radius*
- *Steady-state wide q-profile reversal*
- *P_{ICRH} = 9 MW (sensitivity: a minimum of 6 MW is required)*
- *P_{LH} = 3.7 MW → margin remains on P_{LH}*
- *85 % electron heating; η_{LH} = 1.1 10^{19} A/W/m^2*
- ***100% non-inductive, 40 % bootstrap and 60 % LHCD; $\beta_N \sim 1.7$; $\beta_P \sim 3$; $\rho^* = 4.10^{-3}$***
- ***Very similar q-profile and LH deposition as foreseen for ITER steady-state scenario***

Typical ray rajectory (only 1 ray shown)









Summary

- Access to Type I Elmy H mode is expected with significant margins
  - Taking a margin of 30 % above the most pessimistic LH threshold scaling expression, at high density and magnetic field yields 9 MW for Type I Elmy H mode access, to be compared with 15 MW coupled
  - ν^* pedestal as in ITER, ρ^* core = 4.10^{-3}

→ guarantees the main WEST scientific target: Tungsten Divertor operating in ELMy H mode over long durations (30 – 60 s)

- In addition, WEST can address steady-state tokamak scenario issues with Tungsten Divertor operation
  - Steady-state wide q-profile reversal, similar to foreseen ITER steady-state scenario
  - Far off-axis LHCD in Type I Elmy H mode with ITER relevant technology
  - Impurity behaviour with dominant electron heating (interesting to check on long time scales !)
  - ITB compatibility with Type I Elmy H mode in Tungsten environment

Perspectives for further Integrated Scenario Modelling

- Tungsten transport and accumulation in H-mode over long durations
  - Source from the edge / pedestal
  - Transport in the plasma core
  - Model for radiative power
- More exploration of advanced scenarios
  - High power, high bootstrap fraction
  - Control q-profile over long duration
- Explore scenarios with less injected power (margins)
- Vary pedestal assumptions

- The presented studies have been made in the “pre-project” phases of WEST
- The WEST project is being launched, in an international context. Modelling is part of the scientific programme preparation.
- ISM members are welcome to participate