Associazione EURATOM ENEA sulla Fusione

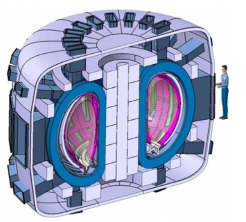
Divertor Studies for FAST, a proposed European satellite tokamak for the fast track to fusion

V. Pericoli Ridolfini[a], B. Viola[a], R. Zagórski[b], G. Calabrò[a], F. Crisanti[a], G. Maddaluno[a]

[a]Associazione ENEA-EURATOM sulla Fusione, CR Frascati, Via Enrico Fermi 45, 00044 Frascati (Roma) Italy; [b]Institute of Plasma Physics and Laser Microfusion, EURATOM/IPPLM Association, Warsaw, Poland

Abstract. The first simulations with EDGE2D/EIRENE code of the SOL plasma in the FAST tokamak, which will be relevant for both ITER and DEMO, have been run for the reference and extreme H-mode scenarios. The whole envisaged range of density values at the separatrix $n_{s,out}$=0.7-2.0×10^{20} m^{-3} has been considered. The reference divertor and 5 different preliminary alternatives have been considered in order to single out the crucial factors for optimizing the design. These are both the plate tilting angle and the neutral dynamics, as it results from the comparison of their characteristics. Projections suggest that full detachment is possible for the higher density scenario, while for the full non-inductive operation the injection of impurity will probably be necessary to reduce the heat load.

FAST
Fusion Advanced Studies Tokamak
Main parameters



Plasma Current (MA)	≤ 8
B_T(T)	≤ 8.5
Major Radius (m)	1.82
Minor Radius (m)	0.64
Elongation k_{95}	1.7
Triangularity δ_{95}	0.4
Safety Factor q_{95}	3
V_p (m^3)	23
<n>(m^{-3})	≤ 5.5x10^{20}
Flat-top B_T (s)	15 -> 170
H&CD power (MW)	40
ICRH	30 (->15)
ECRH	4 (->15)
LH	6
NNBI	10 ?
P/R (MW/m)	22

All the ITER plasma scenarios are foreseen

FAST	H-mode reference	H-mode extreme	H-mode ECRH	Hybrid	AT	AT2	Full NICD
I_p (MA)	**6.5**	8.0	**6**	5	3	**3**	2
q_{95}	3	2.6	2.8	4	5	3	5
B_T (T)	**7.5**	8.5	**6.5** *(6.7)*	7.5	6	**3.5**	3.5
H_{98}	1	1	1	1.3	1.5	1.5	1.5
<n_{20}> (m^{-3})	2	5	2	3	1.2	1.1	1
P_{th_H} (MW)	14 ÷ 18	22 ÷ 35	14 ÷18	18 ÷ 23	8.5 ÷ 12	5 ÷ 7	5 ÷ 7
β_N	1.3	1.7	1.4	2.0	1.9	3.2	3.4
τ_E (s)	0.4	0.65	0.38	0.5	0.25	0.18	0.13
τ_{res} (s)	5.5	5	5	3	3	5 ÷ 6	2 ÷ 5
T_0 (keV)	13.0	9.0	11	8.5	13	13	7.5
Q	0.65	1.5	0.5	0.9	0.19	0.14	0.06
$t_{discharge}$ (s)	20	13	26	20	70	170	170
$t_{flat-top}$ (s)	13	2	17	15	60	160	160
I_{NI}/I_p (%)	15	15	20	30	60	80	>100
P_{ADD}(MW)	30	40	15+15	30	30	40	40

One of the main FAST mission: to study the plasma-wall interaction under ITER relevant conditions AND in view of DEMO

The divertor problematic approached in two ways that eventually should converge

a)Preliminary engineering design of a "plausible" divertor

b) to "find out" an optimized ideal divertor

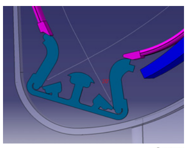
Two computing tools used:

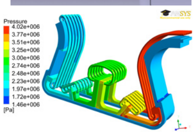
1)COREDIV that couples the plasma bulk with the plasma EDGE (1D in the bulk and 2D in the SOL); good physics but the actual geometry not included

2) EDGE2D/EIRENE describes the energy in the plasma EDGE including the actual FW and divertor geometry; but there is no description/interaction with the plasma bulk

a) DIVERTOR ENGINEERING

- Divertor design with outer strike angle ~ 20°
- Composed by a removable cassette body mounted on the Vacuum Vessel
- Each divertor module covers 5 degrees for a total of 72 elements
- Each module composed by 6 row of monoblock W
- Each row individually cooled by water flowing at $20 ms^{-1}$ in 12mm diameter pipes of CuCrZr (1mm layer of OFHC)
- Preliminary thermal analysis (3D) using ANSYS CFX





Maximum load $P_{load,max}$=18 MW/m^2 continuous

b) Physics I - COREDIV OUTPUT

PFC material	W				W +Ar			L-Li+Ne
Scenario	H-mode reference	H-mode extreme	Full NICD		H-mode reference	H-mode extreme	Full NICD	H-mode reference
I_p (MA)	6.5	8	2		6.5	8	2	6.5
B_T (T)	7.5	8.5	3.5		7.5	8.5	3.5	7.5
<n_e> ($10^{20}m^{-3}$)	2	5	1.0	1.3	2	5	1.0	2
T_0 (keV)	13.0	9.0	7.5		13.0	9.0	7.5	13.0
P_{ADD} (MW)	30	40	40		30	40	40	30
COREDIV output								
Ar (Ne) (%)	–	–	–		0.03	0.02	0.6	0.68
$n_{e,sep}$($10^{20}m^{-3}$)	0.73	1.67	0.29	0.40	0.76	1.75	0.32	0.92
Z_{eff}	1.1	1.0	2.4	1.7	1.4	1.1	3.6	1.8
f_{rad} (%)	19	21	72	64	57	46	92	31
T_{plate} (eV)	57	32	86	76	17	6	10	34
P_{DIV} (MW)	22.7	32.5	9.2	12.2	11.7	17.8	2.2	17.1
q_{target} (MWm^{-2})	20.6	29.5	8.3	11.1	10.6	16.1	2.0	15.5

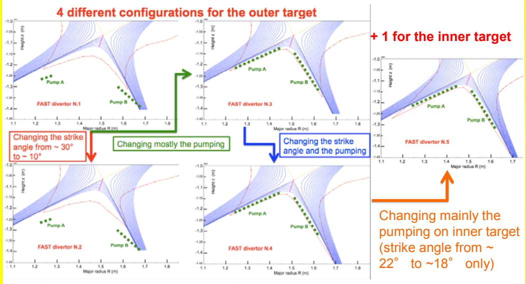
b) Physics II - EDGE2D modelling

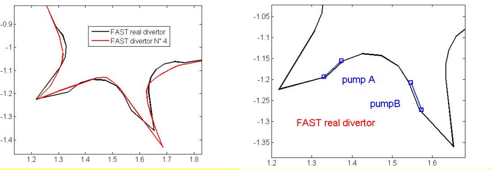
MAIN AIMS:

1) To refine the COREDIV results and confirm the safe use of the W-plate monoblock
2) To see whether and how it could be possible to operate without impurity seeding to exploit the wide variability of f_{rad} (20-95%) and then of P_{SOL}/R

Only reference and extreme H mode considered as first step, **WITH NO ADDED IMPURITY IN THE SOL**

a) Various divertor geometries to investigate the effects of the different neutrals dynamics for shielding the targets and of the different strike angle onto the plates
b) Scan in the density at LCMS to cover the possible values and different input power in the SOL
c) Crosscheck the results for the conceptual designs with the foreseen one





Cases considered (close to the most challenging for the divertor heat load) :

P_{SOL}=20 MW; $n_{e,LCMS}$=0.7, 0.8, 0.9, 1.0, 1.2 ,1.5×10^{20} m^{-3}
(H-mode reference without impurity seeding; H-mode extreme with some impurity)

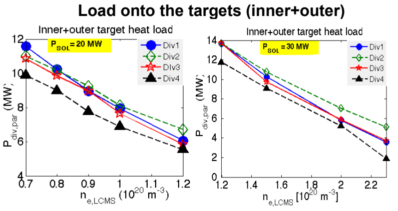
1)P_{SOL}=30 MW; $n_{e,LCMS}$=1.2, 1.5, 2.0, 2.3×10^{20} m^{-3}
(H-mode extreme with no impurity injection)

NOTE : The advanced scenario is less challenging for the divertor heat load since a non negligible radiation fraction from intrinsic impurity (W) is unavoidable

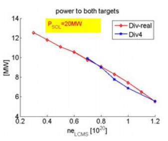
Perpendicular transport coefficients reference values:

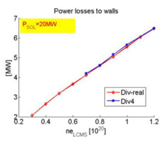
$D_\perp$= $\chi_{i\perp}$=0.5 m^2/s; $\chi_{e\perp}$=1.0 m^2/s (Conservative assumption)

GLOBAL BEHAVIOUR – POWER LOADS



From the deposition profiles (on the top right) any divertor design is **Acceptable** for P_{load}<8 MW



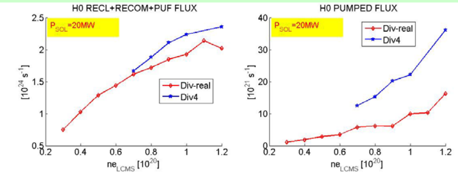


- ➢Regular decrease with $n_{e,LCMS}$
- ➢ The neutrals dynamics has the larger effect

FOR ANY DENSITY

- ➢ Modifying the inner divertor affects mostly the loss to the vessel walls
- ➢ Modifying the outer divertor affects the other losses as ionization and CHX
- ➢ **Margins for optimizing the design exist**

GLOBAL BEHAVIOUR – PUMP MODELLING

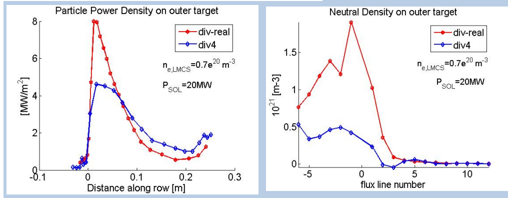


Different pump dynamic due to position and surface

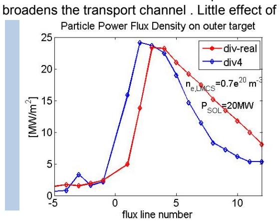
PROFILES onto the OUTER TARGET - P_{SOL}=20MW

$n_{e,LCMS}$= 0.7×10^{20} m^{-3}

Actual total load onto the target surface — *Neutrals density*



|| fluxes enlighten physics: it changes only when the neutral dynamics changes: with Div 4 & 5 a neutral cushion builds up that shifts the deposition peak, depresses it and broadens the transport channel . Little effect of the strike angle variation (div. 1,2,3).

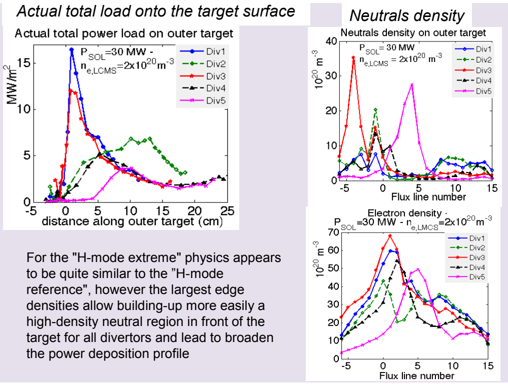


The effect of the "neutral channel" clearly visible on both T_e and n_e. At strike point T_e is depressed and n_e is increased. Partial detachment already at this "low" density

PROFILES onto the OUTER TARGET - P_{SOL}=30MW

$n_{e,LCMS}$= 2.0×10^{20} m^{-3}

Actual total load onto the target surface — *Neutrals density*

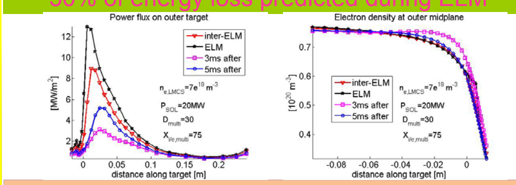


For the "H-mode extreme" physics appears to be quite similar to the "H-mode reference", however the largest edge densities allow building-up more easily a high-density neutral region in front of the target for all divertors and lead to broaden the power deposition profile

TRANSPORT COEFFICIENTS

Increasing particle transport does alleviate the load problem, more than increasing thermal diffusivity. Doubling $D_\perp$ reduces by ~40% the peak load and by a factor ~2 the peak of T_e, while affects only by ~20% the peak of density

ELMs modelling - Preliminary simulations: 30% of energy loss predicted during ELM



CONCLUSIONS

with conservative perpendicular transport coefficients

With P_{SOL}=20 MW (⇔P_{rad}~50% in the advanced scenario and P_{rad}~35 - 45% in the reference H-mode) power loads on the outer target become fully manageable for the whole working density range if:

- *the strike angle is decreased to the minimum allowed by the alignement tolerance*
- *some impurity radiating in the edge (as Ne) would be added to have an important fraction of P_{rad} in the SOL*

• With P_{SOL}=16 MW (⇔P_{rad}~60% in the advanced scenario and P_{rad}~ 45 - 55% in the reference scenario) the situation improves remarkably

•With P_{SOL}=30 MW (⇔P_{rad}~25% in the H-mode extreme) the heat load on targets are tolerable for all divertors provided density at LCMS is $n_{e,LCMS}$≥2×10^{20} m^{-3}.

• A large neutral density close to the strike point that builds up in the closer configurations strongly helps not only in lowering the total load but also in broadening its radial deposition

• A careful design of the inner target could significantly increase the power lost to the wall (physics being investigated)

FURTHER OPTIMIZATION OF THE ENGINEERING REFERENCE DESIGN OF THE DIVERTOR IS POSSIBLE