INFLUENCE OF THE IMPURITIES IN THE HYBRID DISCHARGES WITH HIGH POWER IN JET ILW

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ABSTRACT

The aim of work is to numerically study the influences of the impurities in the hybrid discharge with high power in the JET ILW in DD and DT scenarios. Numerical simulations with the COREDIV code of hybrid discharges with 32MW auxiliary heating, 2.2MA plasma current and 2.8T toroidal magnetic field in the ITER-like wall (ILW) corner configuration are presented. In the simulation 5 impurities species are used: intrinsic (beryllium (Be) and nickel (Ni)) from wall, He from reaction DT, tungsten (W) from divertor) and extrinsic neon (Ne) or argon (Ar) by gas puff. The extrapolation to DT and TT plasmas at the original input power of 32 MW and taking into account only the thermal component of the alpha-power, doesn't show any significant difference regarding the power to the target with respect to the DD case.

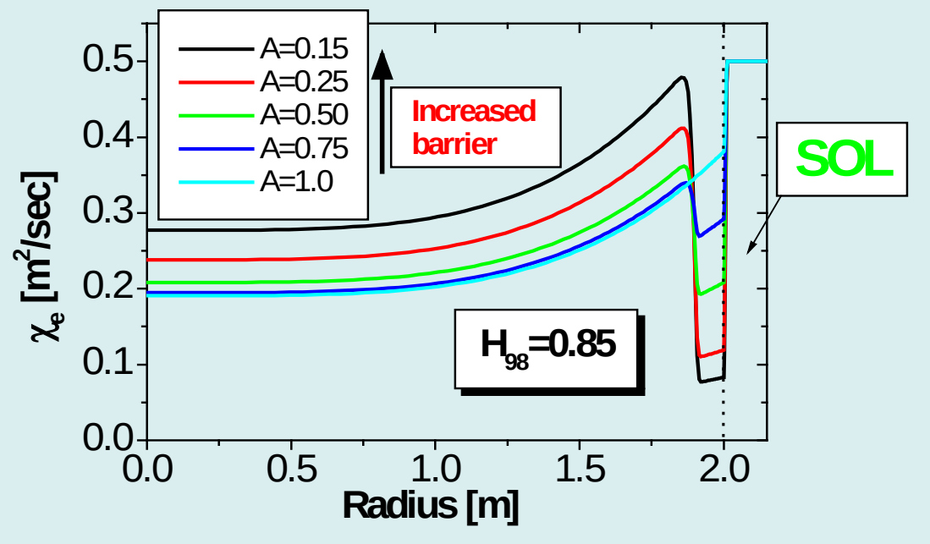
Energy balance equation with transport modelled to reproduce τ_E defined by ELMy H-mode scaling

$$\frac{3}{2}\frac{\partial n_e T_e}{\partial t}+\frac{1}{rg_1}\frac{\partial}{\partial r}\left[rg_2\left(-k_e\frac{\partial T_e}{\partial r}+\frac{5}{2}\Gamma_e T_e\right)\right]=P_{OH}+P_{AUX}+P_\alpha-P_B-P_{synch}-P_{lin}-P_{ion}-Q_{ei}$$

Transport coefficients with prescribed profiles:

$$\boxed{\chi_{e,i}^{an}=C_{e,i}\frac{a^2}{\tau_E}\times\left(0.25+0.75\left(\frac{r}{a}\right)^4\right)\times F_B(r)}$$

$$\boxed{D_i=0.35\chi_e}$$



Main ions density:

$$\frac{\partial n_i}{\partial t}+\frac{1}{rg_1}\frac{\partial}{\partial r}\left[rg_2\left(-D_i\frac{\partial n_i}{\partial r}+n_i v^i_{pinch}\right)\right]=S_i(r)$$

Impurity ions:

$$\frac{\partial n_j^k}{\partial t}+\frac{1}{rg_1}\frac{\partial}{\partial r}\left[rg_2\left(-D_j^k\frac{\partial n_j^k}{\partial r}+n_j^k v_{j,pinch}^k\right)\right]=n_e\left[n_{j-1}^k\alpha_{ion,k}^{j-1}-n_j^k(\alpha_{ion,k}^j+\beta_{rec,k}^j)+n_{j+1}^k\beta_{rec,k}^{j+1}\right]$$

Impurity transport: anomalous

$$\Gamma_{i,j}^{an}=-D_{i,j}^{an}\partial n_{i,j}/\partial r+n_{i,k}V_{i,j}^{pinch}\quad V_i^{pinch}=-0.1D_j^{an}(r/a^2)\quad V_j^{pinch}=0\qquad D_j^{an}=D_i$$

In the model we have two options:

1. to fix H_{98} the parameter C_E is adjusted to keep the calculated confinement time obtained from the solution equal to the value defined by the scaling law in absence of impurities
2. to fix C_E (and thus $\chi_{e,i}^{an}$) and therefore the confinement will be changed accordingly with changes to the seeding level.

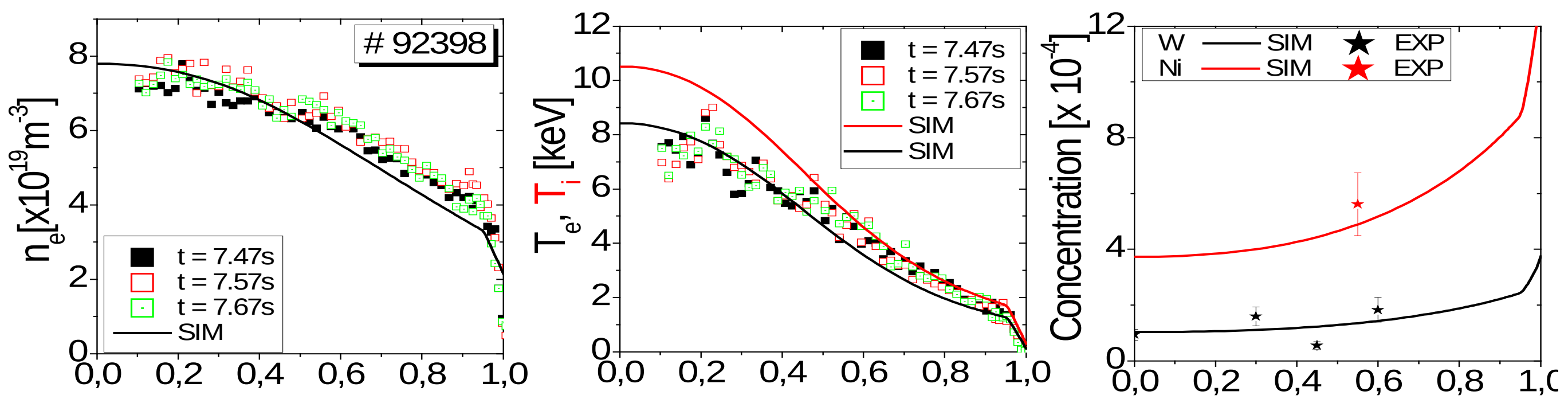
By increasing the radiation with impurity seeding, the net heating power decreases, thus when using the first option transport is reduced in order to keep the total plasma energy constant.

Boundary conditions: n_i, n_z, T_e, T_i – from SOL model P_{inp}, G_{inp} – calculated from core model

SOL PLASMA

- ❑ **2D multifluid transport based on Braginskii equations**
- ❑ **Particle balance, parallel momentum, two energy equations**
- ❑ **Transport: parallel - classical, radial -anomalous**
- ❑ **Slab geometry (lack of PR), drifts neglected**
- ❑ **Atomic processes: ionization, recombination, excitation, charge exchange**
- ❑ **Analytical model for neutrals accounts for plasma recycling and impurity sputtering.**
- ❑ **Boundary conditions: sheath, decay lengths; input fluxes from core model**
- ❑ **Intrinsic and seeded impurities – gas puff at different positions**

EXPERIMENT AND SIMULATIOS FOR DD PLASMA



Experimental and simulated electron density and electron (and ion) temperature profiles, W and Ni concentration for # 92398 t= 7.5s

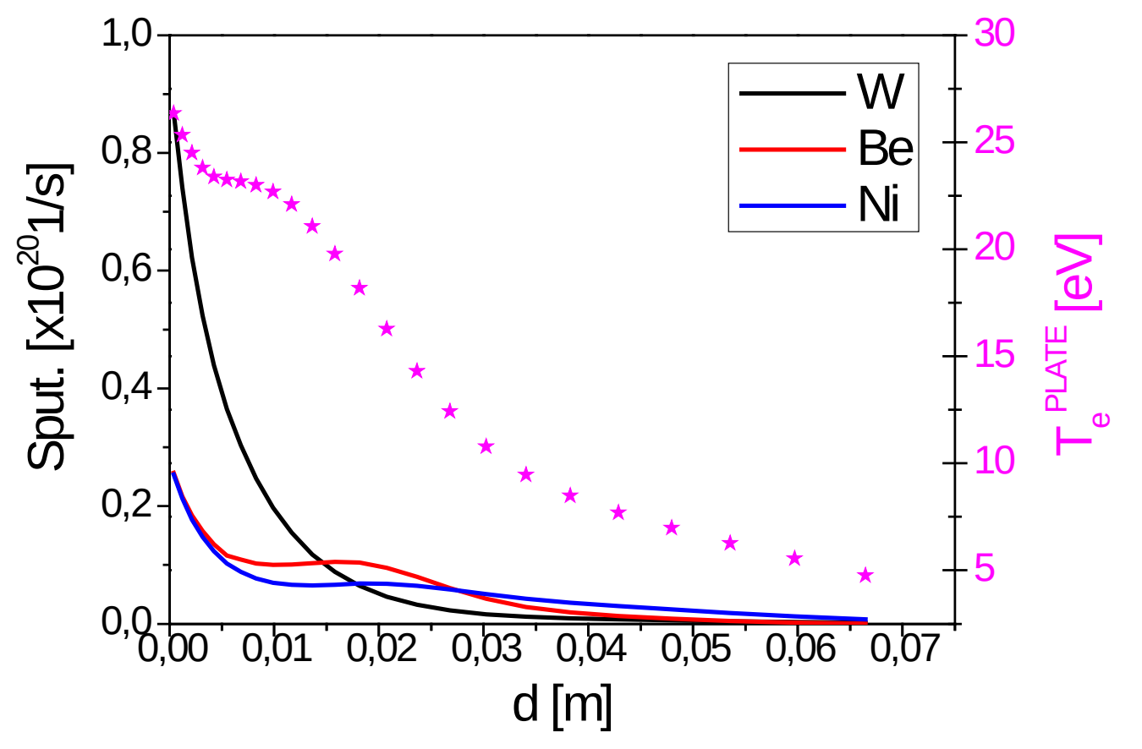
We have good comparison with experimental results for total, core and SOL radiation, W and Ni concentration. The main contributors to increase of Z_{EFF} is Ni and W, which is effect of the high electron temperature. For normalize radius of 0.5 the dominating ionization state for Ni is Ni^{26+} , but for W is W^{44+}.

EXTRAPOLATION FOR DT AND TT PLASMA WITHOUT IMPURITY SEEDINGMODELING RESULTS

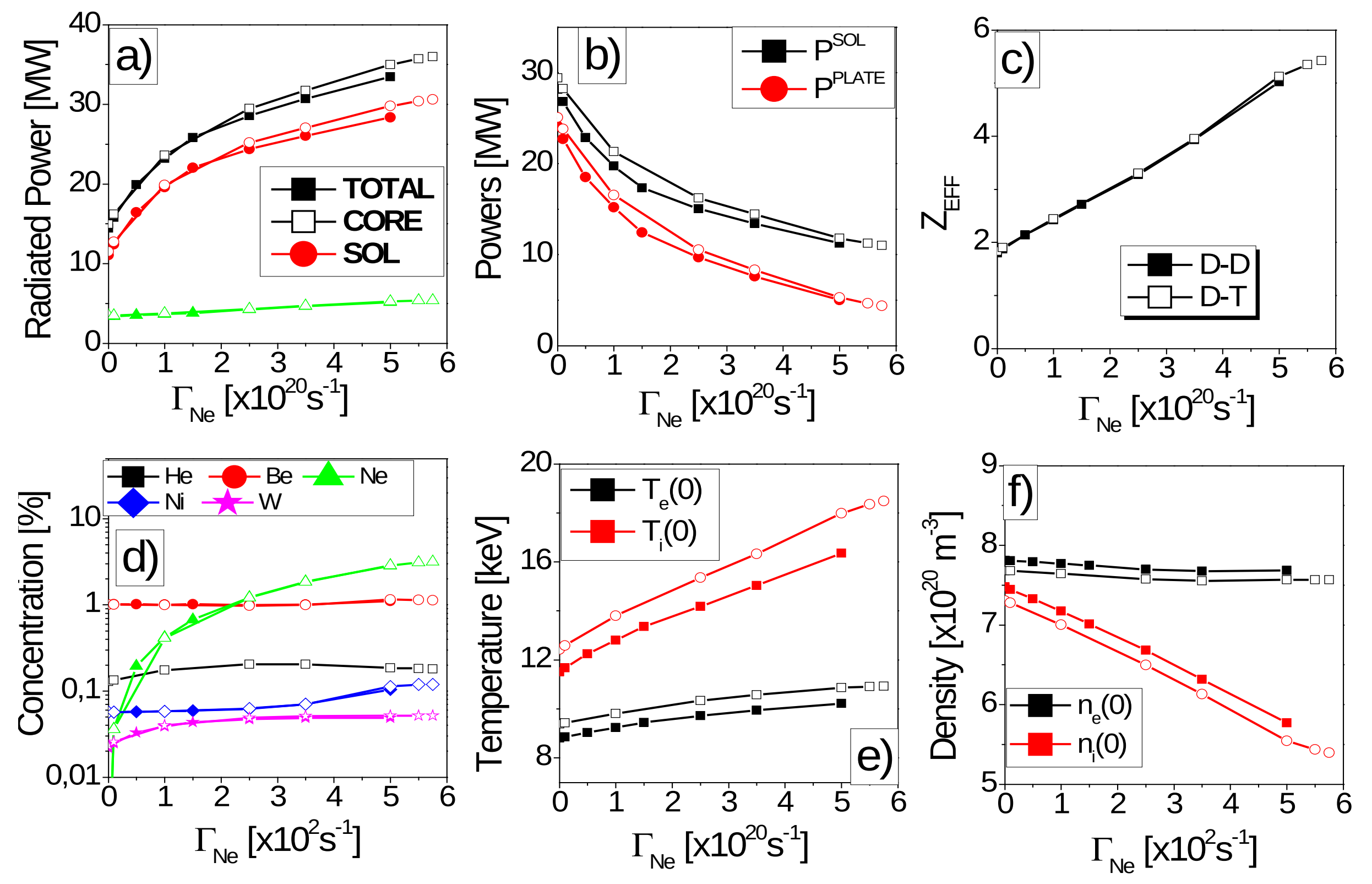
Table : Predictive simulations for DT and TT plasmas at 32 MW.
*By * siimulation with Ni puff (Γ_{Ni} = 1.2x10²⁰atm/s.*

PARAMETERS	D - D	D - T	T – T	T – T
	SIM	SIM	SIM	SIM
P_α^{th}[MW]		0.96		
R^{TOTAL}[MJ]	11.86	11.84	11.34(13.08*)	13.5 (15*)
R^{CORE} [MW]	8.7	8.6	8.11 (9.55*)	10.1 (11.35*)
Z_{EFF}	1.7	1.72	1.7 (1.9*)	1.85 (2.05*)
P^{PLATE} [MW]	20.14	20.16	20.66 (19*)	18.5 (17*)
C_W [x10⁻⁴]	1.55	1.56	1.44 (1.5*)	1.88 (1.9*)
C_{Be} [%]	1	1	1	1
C_{He} [%]	0	0.11	0	4.6%
C_{Ni} [x10⁻⁴]	5.7	5.7	5.8 (9.2*)	5.8 (9.45*)
W sput by D(T) [x10¹⁹1/s]	0	0	0	0
W sput by He [x10¹⁹1/s]	0	0.01	0	0.9 (0.07)
W sput by Be [x10¹⁹1/s]	2.56	2.6	2.5 (2.15*)	2.5 (2.18*)
W sput by W [x10¹⁹1/s]	4.41	4.6	3.9 (3.6*)	4.6 (4.1*)
W sput by Ni [x10¹⁹1/s]	2.5	2.5	2.4 (3.14*)	2.18 (2.9*)
T_e^{PLATE} [eV]	26.3	26.2	25.1 (23.4)	28.3 (26.3)

- ❑ Increase of the He concentration to 4.6% leads to increase: W production by sputtering from helium, W concentration (C_W), radiation in the core increases by 20% and Z_{EFF} from 1.7 to 1.85.
- ❑ Comparing the cases with lower and higher Ni puff observed small increase in W concentration, but total radiation increases by about 1.5MW, which is the consequence of the increase of the Ni radiation.
- ❑ It is observed, that although Ni and Be have different concentrations (C_{Be} 18 times higher), their effect on the W sputtering is similar



EXTRAPOLATION TO DT PLASMA WITH Ne AND Ar IMPURITY SEEDING

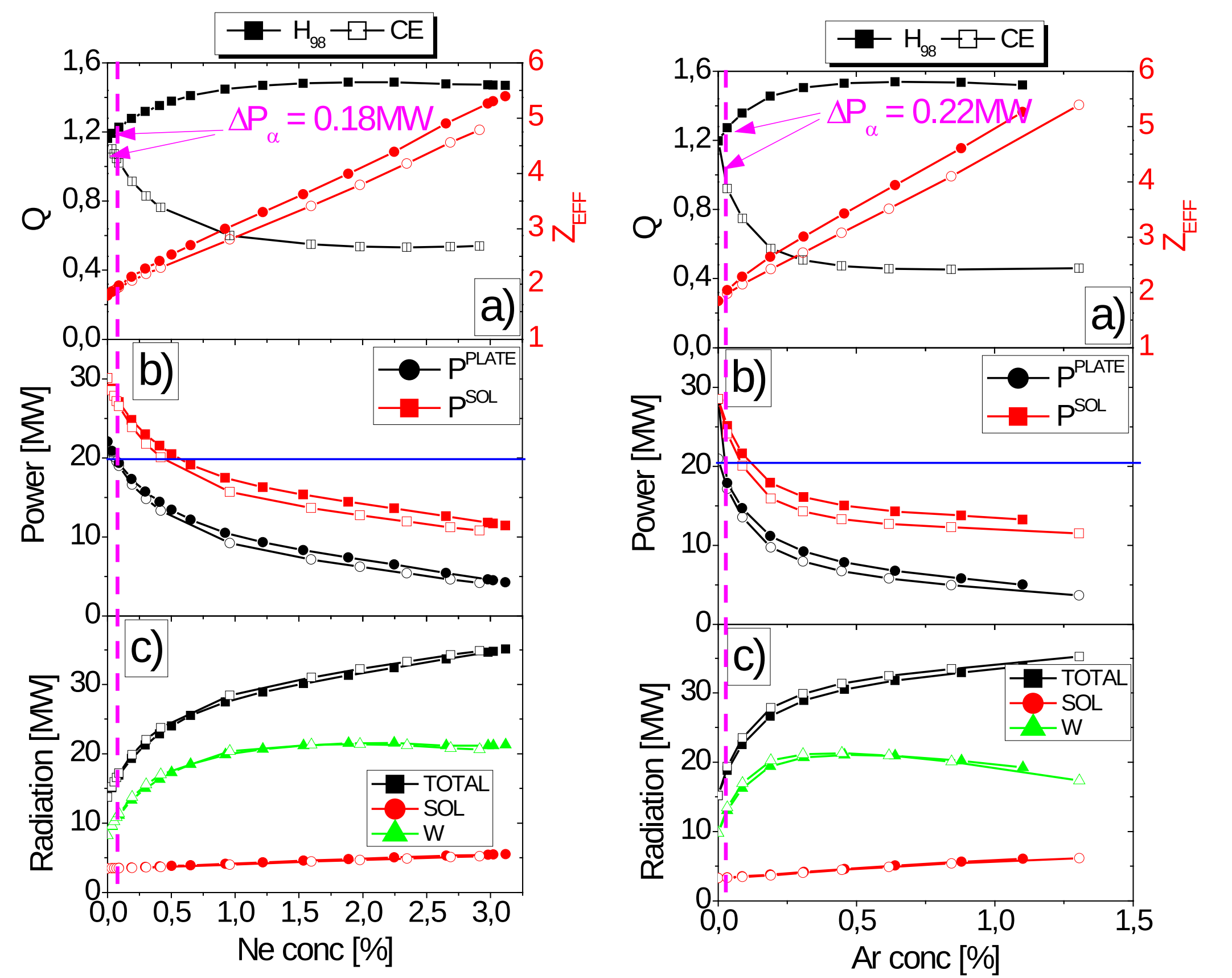


Main code outputs: a) radiation, b) power to the plate and to SOL, c) effective charge state, d) impurity concentration, e) temperature and f) density in centrum for DD (full symbol) and DT (open symbol)as a function of Ne gas puff level

- ❑ For 39MW auxiliary heating, recalling that in our simulations only Pα arising from thermal reactions is accounted for, the simulations indicate that radiation is 13.7 MW without impurity seeding, which gives radiation fraction ~ 35%.
- ❑ From our simulation for DT plasma the thermal α-power is 0.96MW, but if you assume that thermal α-power it is only 35% of the total α-power, the resulting total fusion power will be about 13.7MW.
- ❑ The need for impurity seeding is not overstated.
- ❑ T_e^{PLATE} in the strike point is about 25 – 26eV in simulation, which is lower than T(D) sputtering threshold and consequently sputtering due to D and T is negligible.
- ❑ Very small differences between DD and DT in the radiation profile .

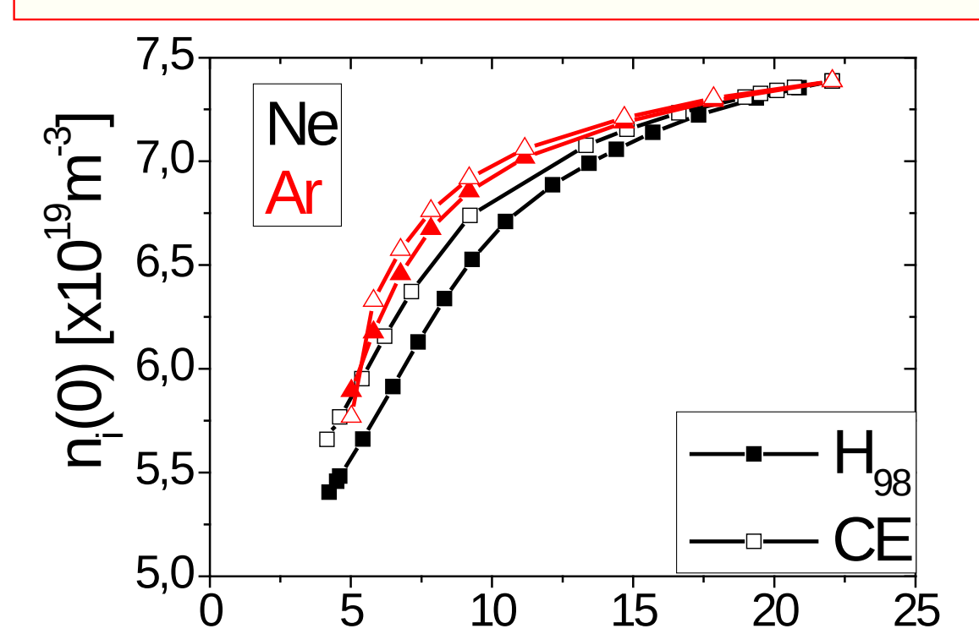
Simulation prepare with two different transport schemas:

1) H_{98} constant → energy constant, <β> constant
2) CE constant → energy (H_{98}), confinement changes

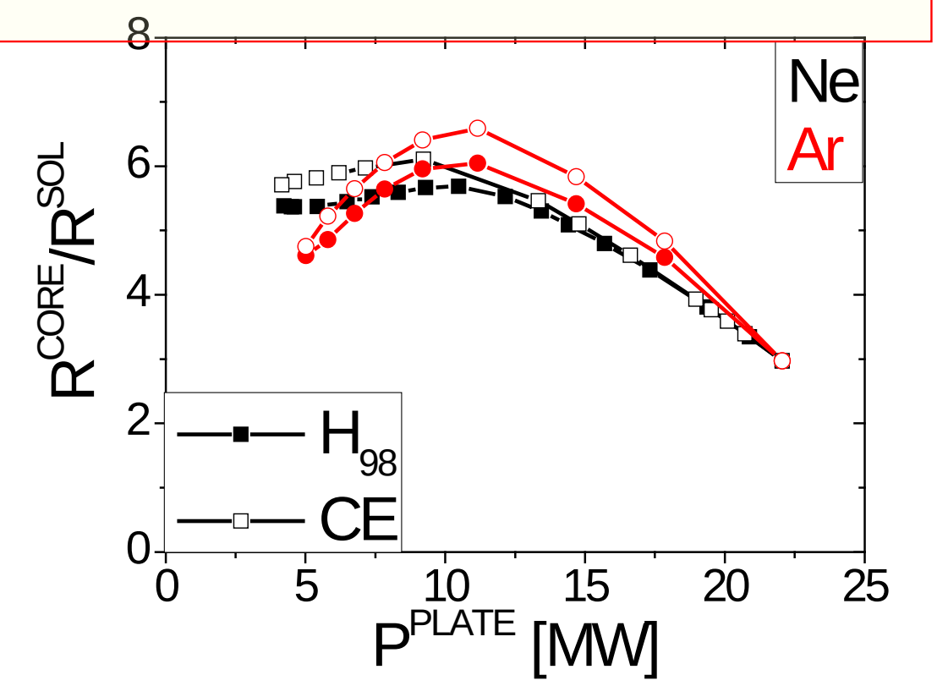


Plasma parameters: a) Q – factor and Z_{EFP}, b) power to the plate and to SOL, c) total, SOL and W radiation, for H_{98} = constant (full symbol) and CE = constant (open symbol) as a function of Ne (left panel) and Ar (right panel) concentration

- ❑ In the case, where H_{98} is constant, we observe increase in the ion temperature with increasing the impurity puff. This has positive effect on the alpha (fusion) production, which increases from 0.96 (4.8) MW to 1.5 (7.5) MW for Ne case.
- ❑ For the case with transport scheme CE =const, when P^{PLATE} is 20MW, H_{98} will be lower by about 0.08 and 0.12 for Ne and Ar puff, respectively.
- ❑ Smaller dilution for both assumptions for the case with Ar seeding is observed.



Ion density in plasma centre for Ne and Ar seeding for both transport scheme.



The R^{CORE}/R^{SOL} for Ar and Ne seeding for both transport scheme.

CONCLUSIONS:

- ❑ **The COREDIV code has been used to perform self-consistent core-edge simulations of DT and TT plasmas.**
- ❑ **Extrapolation to higher auxiliary heating and DT operation shows decisive influence of the power on plasma parameters: increase of the W concentration and radiation in the core by about 25%.**
- ❑ **Tungsten is produced only due to impurities (Be, Ne, Ni)+self-sputtering.**
- ❑ **Extrapolation to DT plasmas, keeping unchanged input power, leads to little difference with respect to the reconstructed DD pulses, with thermal alpha-power.**
- ❑ **In the case with Ar seeding lower plasma confinement is predicted.**

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