13th Joint Workshop on Electron Cyclotron Emission and Electron Cyclotron Resonance Heating, Nizhny Novgorod, Russia, May 17-20, 2004

Electron Cyclotron Radiation Studies Using the ASTRA Transport Code Coupled with the CYTRAN Routine

F. Albajar[1], M. Bornatici[2], G. Cortés[1], J. Dies[1], F. Engelmann[3], J. García[1], J. Izquierdo[1]

[1]Fusion Energy Engineering Laboratory (FEEL) Departament de Física i Enginyeria Nuclear, Universitat Politècnica de Catalunya,

[2]INFM, Dipartimento di Fisica "A.Volta", UNIVERSITÀ DI PAVIA

[3] Max-Planck-Institut für Plasmaphysik

INTRODUCTION

To operate **next step tokamaks** and **reactors in steady-state and at high fusion gain Q(≳ 5)** is required:

- **Good confinement** properties
- **High temperature** (T_e > 30 keV)

In such regimes the **importance of the effects of EC waves increases**

➡ **It is necessary** to take the non-local character of EC wave transport, **due to wall reflection and re-absorption**, into account

(not covered by global models as usually applied)

OBJECTIVE OF THIS STUDY

To analyse the impact of the EC wave transfer in the local power balance and on the temperature profile of an ITER-like steady-state tokamak

TOOLS/DESCRIPTION OF THE MODEL

ASTRA Transport Code ↔ CYTRAN Routine *(a reasonable approximation to more exact approaches to describing EC non-local effects)*

$$\frac{dP_{\alpha,e}}{dV}+\frac{dP_{ext}}{dV}-\frac{dP_{e\to i}}{dV}=\frac{dP_{B}}{dV}+\frac{dP_{EC}}{dV}+\frac{dP_{con,e}}{dV}$$

α-power coupled to e⁻ and i; external power; e⁻ and i heat exchange; Bremss. loss; net EC radiative loss; e⁻ and i conductive-convective loss

$$\frac{dP_{\alpha,i}}{dV}+\frac{dP_{e\to i}}{dV}=\frac{dP_{con,i}}{dV}$$

(local) steady-state power balance

Thermal diffusivities: a phenomenological model

$$\chi_e=\chi_i=C\,f(\rho)\left[1-H(\rho-\rho_1)\right]F(s)+\chi_{i,neo},$$

H: 1 up to ρ_1, 0 in the range $\rho_1<\rho<1$

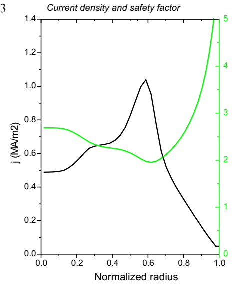
$f(\rho)=1+3\rho^2$

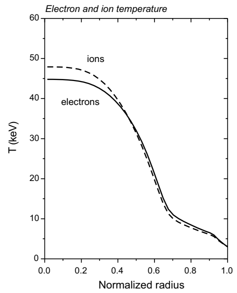
$F(s)=1/(1+\exp(7(1-s)))$

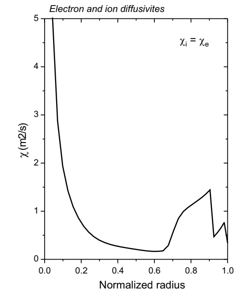
[A.R. Polevoi et al., "Possibility of $Q>5$ stable, steady-state operation in ITER with moderate β_N and H-factor", Proc. 19th Int. Conf. on Fusion Energy, Lyon, 2002]

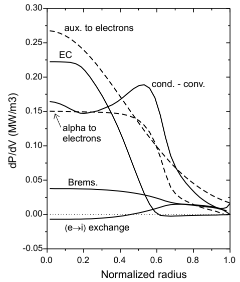
IMPORTANCE OF EC RADIATION IN AN ITER-LIKE STATE SCENARIO

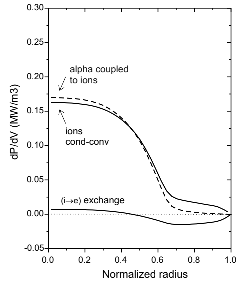
- R = 6.35 m, a = 1.85 m, B_t = 5.18 T, κ = 1.85, δ = 0.4
- $n_e=n_{e0}(1-r^2)^{\gamma_n}$ with $n_{e0}=7\times10^{19}$ m^{-3} and $\gamma_n=0.1$
- α-particle density consistent with $\tau^*_\alpha/\tau_E\approx5$ and $Z_{eff}\approx2$ (impurities: Beryllium and Argon, f_{Be} = 2% and f_{Ar} = 0.3%)
- $\boldsymbol{R_w}$ **= 0.6**
- **Fixed external power** P_{ext} = 68 MW (Gaussian, σ = 1.2 m)
- ***j*** **fitting** ITER studies [B.J. Green et al.] with a total current I_p = 9 MA.







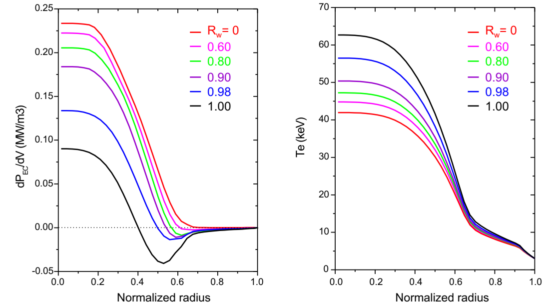




■ **The net EC radiation loss in the plasma core** effectively **provides the most important cooling mechanism for electrons** ⇒ for ρ = 0 {$(dP_{EC}/dV)/(dP_{con,e}/dV)\simeq1.3$; $(dP_{EC}/dV)/(dP_B/dV)\simeq6$}

Importance on determining whether $T_e<T_i$ or $T_i<T_e$

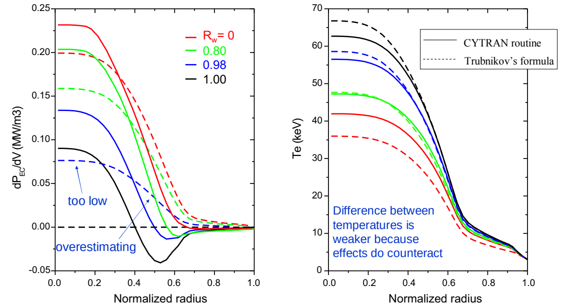
DEPENDENCE OF EC WAVE COOLING ON THE WALL REFLECTION COEFFICIENT



■ when R_w ↗ {dP_{EC}/dV ↘ (due to self-absorption); EC profile reversal becomes dominant in the cooler plasma edge} ⇒ strength of T_e-gradient ↗ (in the net EC absorption region) } T_e ↗ (at the plasma centre)

sizeable for (R_w ≳ 0.6)

Comparison of the results obtained using the **CYTRAN** routine with those following from locally applying **Trubnikov's global formula** …



CONCLUSION

For next-step and reactor-grade tokamak in steady-state operation the **net EC wave emission tends to provide the most important cooling mechanism for electrons in the plasma core**. Describing the EC wave power transfer with sufficient accuracy and, in particular, covering properly non-local effects deriving from wall reflection and re-absorption, is therefore essential in modelling the plasma power balance. While the core electron temperature is quite sensitive to changes in electron heating and/or cooling in the regime in question, **the dependence on the wall reflection coefficient is sizeable only for** $\boldsymbol{R_w\gtrsim0.6}$.