

# Modelling of the density limit in the W7-AS Stellarator

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## 1 Introduction

Density limit discharges in the W7-AS stellarator, with constant line integrated density and a duration of up to 2 seconds, collapse due to the decreasing net power to the plasma when the centrally peaked radiated power density exceeds that of the deposited power density. Simulations of this scenario show that peaked impurity density profiles are responsible and this arises as the ratio of inward pinch velocity to diffusion coefficient measured by laser blow off measurements in W7-AS with aluminium increases with increasing density. A series of simulations with variations of input power, density, magnetic field, impurity influx rate and ratio of inward pinch velocity to diffusion coefficient have been carried out.

Empirical studies of the energy confinement time in stellarators have been summarized in the form of an international scaling law, ISS-95. In this scaling law, the energy confinement time is given by [1] :

$$\tau_{ISS95} = 0.079a^{2.21}R^{0.65}P_{abs}^{-0.59}\bar{n}_e^{0.51}B_o^{0.83}t_{2/3}^{0.4} \quad (1)$$

with units in s, m, MW,  $10^{19} \text{ m}^{-3}$  and T.

The maximum achievable density in density limit experiments from the magnetic field and power input variation over the last four years of operation show that the critical density,  $n_c$ , can be fitted by a power law fit with respect to the volume averaged absorbed power,  $P_{abs}/V_p$  [MW/m<sup>3</sup>], and B [T] :

$$n_c = 1.46 \pm 0.07(P_{abs}/V_p)^{0.48 \pm 0.03} B^{0.54 \pm 0.05} [10^{20} \text{ m}^{-3}] \quad (2)$$

Combining these scaling laws one can arrive at the following scaling law for the thermal heat conductivity,  $\chi_e$  :

$$\chi_e = a^2/\tau_e \propto P_{abs}^{0.83} B_o^{-0.55} \quad (3)$$

for discharges at constant volume. For comparisons of stellarators with different plasma volumes it can be seen that a scaling of the critical density with volume should be expected [2, 3].

## 2 Simulations

Using the above scaling law, a series of discharges at constant density were simulated. By scaling  $\chi_e$  appropriately, the effects of a power or magnetic field scan on the density limit could be simulated. In W7-AS, the dominant impurities are carbon and chlorine. Constant influx rates of impurities at the plasma boundary and the radial profiles of the diffusion coefficient, D, and inward pinch, v, measured in laser blow off experiments with aluminium were assumed in the simulations. The steady increase of centrally radiated power due to the peaking of the impurity ions, consistent with experimental observations, could be demonstrated.

The sensitivity of the discharge collapse to variations in the impurity influx rate at the boundary and the ratio v/D were investigated. Experimentally it was found that the decay time of injected Al, and hence v/D, increases with increasing  $\bar{n}_e$  and  $B_o$  and decreases with increasing  $P_{abs}$  [4].

Furthermore it is to be expected that the impurity influx rates at the plasma boundary are a function of the edge plasma parameters.

For  $P_{abs} = 380$  kW,  $n_{eo} = 6.2 \times 10^{19} \text{ m}^{-3}$  and  $B_o = 2.5$  T assuming  $\chi_e = 0.3 (1 + 10 \cdot (r/a)^8) \text{ m}^2/\text{s}$  and  $D$  and  $v$  profiles as measured from Al laser blow off experiments, the radial profiles of the calculated evolution of the radial profiles of electron temperature, radiated power and  $Z_{eff}$  are shown in Figs. 1, 2 and 3 respectively. A one fluid model was assumed. The influx rate of C and Cl at the plasma boundary was assumed constant during the discharge. Simulations confirm that bolometer measurements in the edge plasma would otherwise increase with the resulting increase in impurity density in the plasma boundary. A strong bifurcation in the  $T_e$  profiles is found for this value of  $\chi_e$  consistent with theoretical expectations [2, 3] and experimental results [5].

Features observed in density limit experiments on W7-AS could be reproduced. A density reduction of 7% holding all other variables constant leads to a delay in the collapse time of the discharge. In addition, the peaked  $Z_{eff}$  profiles derived from measurements of bremsstrahlung radiation, shown in Fig. 4, could be validated. As expected, decreasing the impurity influx rate or the ratio  $v/D$  also delays the collapse time of the discharge.

A steady state discharge was possible when assuming impurity influx rate reduction of 50% at the separatrix. Future experiments in W7-AS with a divertor, with expected reductions of the impurity influx rate at the separatrix, will favour therefore steady state scenarios at high density.

## References

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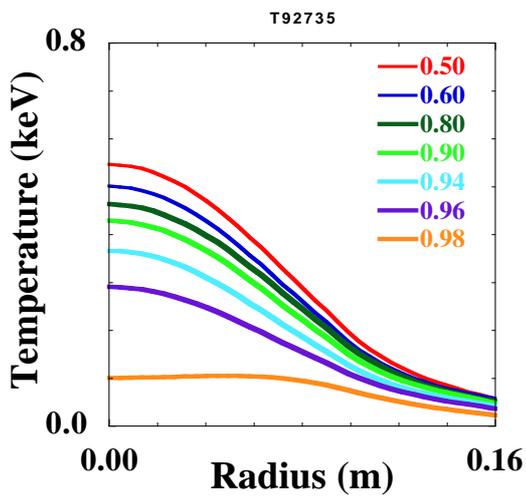


Figure 1: Radial profile evolution of  $T_e$  from simulations.

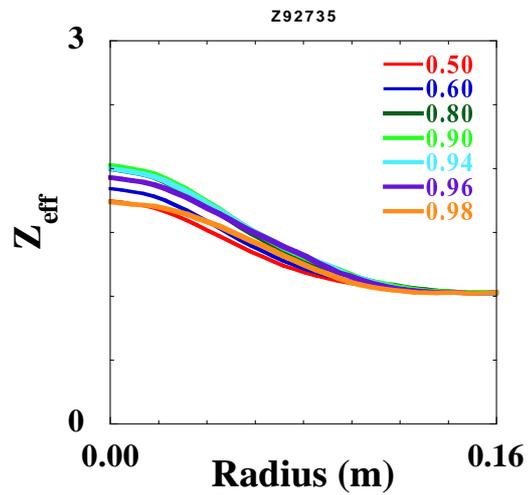


Figure 3: Radial profile evolution of  $Z_{eff}$  from simulations.

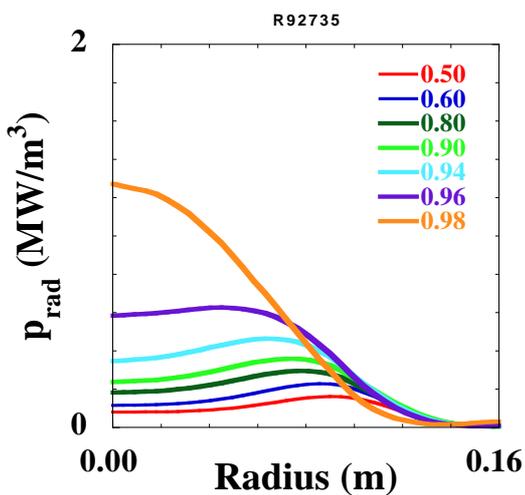


Figure 2: Radial profile evolution of  $P_{rad}$  from simulations.

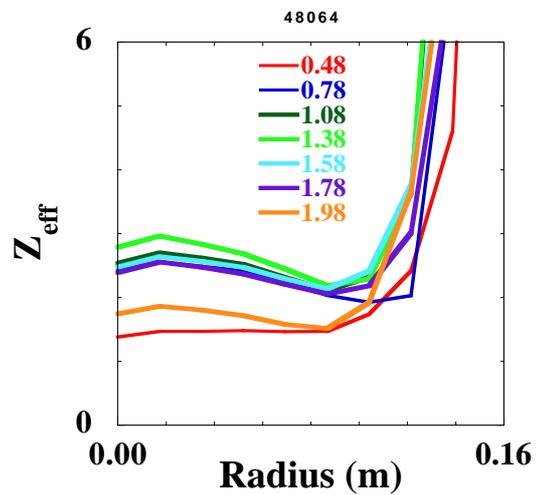


Figure 4: Radial profile evolution of  $Z_{eff}$  measured in density limit experiments.