IMPURITY TRANSPORT STUDIES AT TEXTOR-94

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1. Introduction and overview

The transport of argon was studied at the tokamak TEXTOR-94 by injecting short (2 ms) and small gas puffs. Spectroscopic signals from different ionization stages of argon (Ar VIII, Ar XVI and Ar XVII) were recorded with high time resolution in order to follow the penetration of argon from the plasma edge into the plasma centre. The temporal evolution of the measured spectral lines shows a fast rise followed by a slow decay, where the signals from the higher ionized stages are delayed with respect to the Ar VIII line by typically 5-20 ms. In a series of L-mode discharges heated with constant neutral beam (NBI) power, the mean electron density was varied at two different plasma currents. Radial diffusion coefficients are determined from the experimental data by simulating these experiments using the predictive impurity transport code STRAHL [1].

2. Experimental technique

At the limiter tokamak TEXTOR-94 (major radius R = 1.75 m, minor radius a = 0.46 m, circular plasma shape) a fast piezo-electric valve [2] located at a radial position r = 0.55 m was used to inject a series of up to four short argon puffs, each of them separated by a time interval of 1 second, into the flat top phase of a series of discharges. The temporal shape of these gas puffs is monitored by a fast (0.1 ms) infrared Ar I radiation detector directed towards the gas inlet, yielding a duration of the gas puffs of 2 ms (FWHM). The Ar VIII (Na-like) line radiation at a wavelength of λ = 70.04 nm and the Ar XVI (Li-like) line at λ = 35.39 nm are measured using two VUV/XUV monochromators mounted at radial ports near the horizontal midplane of TEXTOR-94. The Ar XVII (He-like) signals at λ = 0.4 nm (W and Z component) are collected by means of a high-resolution X-ray spectrometer [3], which is installed in the horizontal midplane. All spectroscopic signals are recorded with 0.5 ms time resolution.

3. Typical experimental results

The impurity transport in NBI heated discharges (co-injection) was investigated for two different plasma currents and by varying the mean electron density from shot to shot. As an example, the time traces of TEXTOR shot # 78155 are shown in Fig. 1. During a flat top phase of about 4 seconds length the line averaged electron density n_e, central electron temperature T_e, neutral beam heating power and loop voltage remain constant. At t = 1, 2, 3 and 4 seconds argon is injected into the discharge. While n_e, T_e and the loop voltage are not significantly disturbed by the gas puffs, small peaks are visible in the radiated power signal. The time evolution of the measured normalized line intensities of four different ionization stages are displayed in Fig. 2. In order to reduce the noise, the signals are averaged over the four identical gas puffs within one discharge. All signals show a fast increase (3-30 ms), followed by a slower decay phase (30-300 ms), while the increase of the signals from higher ionization stages is delayed with respect to the lower stages by typically 5 to 20 ms.

4. Data evaluation

The experiments are evaluated by simulating the gas puff experiments using the predictive impurity transport code STRAHL [1], by which the system of time-dependent continuity equations for all ionization stages of a selectable impurity species can be solved numerically in a spatially one-dimensional geometry (flux surface averages). Radial profiles of n_e and T_e as measured by interferometry, ECE and helium beam spectroscopy are used as input parameters, while atomic processes like ionization and line excitation are described using data from ADAS. The radial profiles of the impurity diffusion coefficient D and the radial drift velocity v have to be assumed and are improved iteratively in successive STRAHL runs adjusting the temporal evolution of the calculated line radiation intensities with the measured data.

Under the plasma conditions typical for TEXTOR, the maximum of the Ar VIII line emissivity is found at a radial position r = 0.41...0.45 m (near the LCFS at 0.46 m), while the Ar XVII line radiates only in the plasma centre (r = 0...0.1 m). The Ar XVI line radiation is centred near a value of T_e = 500 eV (r = 0.18...0.25 m, i.e. near r/a = 0.5). Thus the radiation shells of these three lines are spatially separated by typically about one half of the minor radius each. From the temporal shape of the measured line intensities alone it is difficult to deduce the radial distributions of D and v unambiguously. However, the time delay between the onset of the successively higher ionized stages is a measure of the effective particle transport time between the respective radiation shells. Therefore we try to determine two effective diffusion coefficients D_{edge} and D_{core}, which are both assumed to be constant in the outer respective inner radial region of the discharge. For simplicity, the transition point is assumed to be at a constant radial position of r/a = 0.5 for all shots evaluated. As the ratio between convective and diffusive transport is not known, we adopt this ratio as given in [4-6]: $v = -2Dr/a^2$. We further assume that both D and v are equal for all ionization stages of argon. Under these assumptions the effective particle transport time is mainly determined by diffusion, while the convective contribution is small. Radial profiles of D, v and the respective emissivity profiles as evaluated for TEXTOR shot #78155 are depicted in Fig. 3.

5. Results

The scaling of the diffusion coefficients D_{edge} (r /a = 0.5..1) and D_{core} (r/a = 0..0.5) with the mean electron density n_e for constant NBI heating power and for two different discharge currents is displayed in Fig. 4 in a semilogarithmic plot. Varying the electron density, the values for D_{edge} remain nearly constant with average values of D_{edge} = 4.0 m^2/s (I_P = 447 kA) and D_{edge} = 6.5 m^2/s (I_P = 301 kA). These numbers are similar to the value of the Bohm diffusion coefficient valid for the plasma edge region (D_{Bohm} = 5.5 m^2/s for T_e = 200 eV) and more than one order of magnitude larger than the neoclassical diffusion coefficient (D_{neocl} = 0.2 m^2/s for typical plasma edge conditions at TEXTOR-94). The measured energy confinement times are τ_e = 30 ms (I_P = 301 kA) and τ_e = 45 ms (I_P = 447 kA), respectively. Thus we may conclude, that the edge diffusion coefficient and the inverse confinement time scale inversely with the plasma current: $D_{edge} \propto 1/\tau_e \propto 1/I_P$. At low electron densities (n_e = 2...3 $\times 10^{19}$ m^{-3}) the values of D_{core} are near the values of D_{edge} ($D_{core} \approx D_{edge} \approx$ 4...6 m^2/s). Approaching towards higher densities, one observes a well pronounced decrease of D_{core} by about one order of magnitude, reaching a value of $D_{core} \approx$ 0.5 m^2/s at high electron densities (n_e = 4...6 $\times 10^{19}$ m^{-3}). Again the absolute figures of D_{core} are more than one order of magnitude above the values predicted by the neoclassical theory (D_{neocl} = 0.02 m^2/s for typical plasma core conditions at TEXTOR-94).

6. Conclusions

The transport of argon was studied using a fast gas puffing technique and evaluating the measured data using the STRAHL code. The oberved scaling of D_{edge} and τ_e with I_P is in good agreement with earlier results [see, e.g., 5, 7], while the absolute figures of D_{edge} confirm the anomalous nature of the particle transport in the plasma edge region. A remarkable decrease of D_{core} is found with increasing electron density, while D_{edge} is nearly independent from the density. In the future, a more detailed radial structure of the transport properties shall be determined by increasing both the number of measured spectral lines and the time resolution of the diagnostics.

References

[1] Behringer K.: Rep. JET-R(87)08, JET Joint Undertaking (1987)

[2] Bertschinger G. et al.: *Proc. 24th EPS Conference*, Berchtesgaden, 1709 (1997)

[3] Herzog O. et al.: *Proc. 24th EPS Conference*, Berchtesgaden, 1709 (1997)

[4] Gianella R. et al.: Nucl. Fusion **34** 1185 (1994)

[5] Shimada M.: Fus. Engin. And Design **15** 325 (1992)

[6] Fussmann G. et al.: Plasma Phys. Contr. Fusion **33** 1677 (1991)

[7] Wagner F. and Stroth U.: Plasma Phys. Contr. Fusion **35** 1321 (1993)

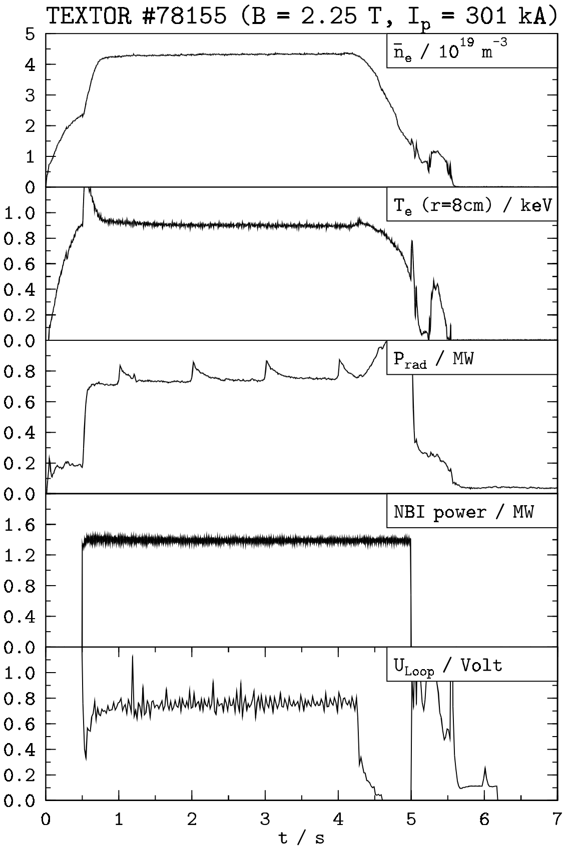

Figure 1: Time traces for argon puffing experiment TEXTOR shot # 78155

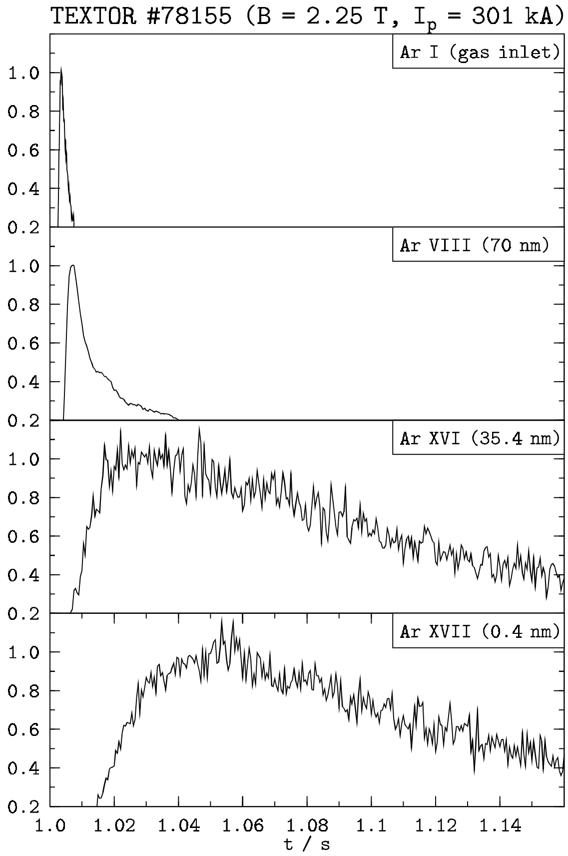

Figure 2: Measured normalized argon line intensities after a gas puff at t = 1.0 sec.

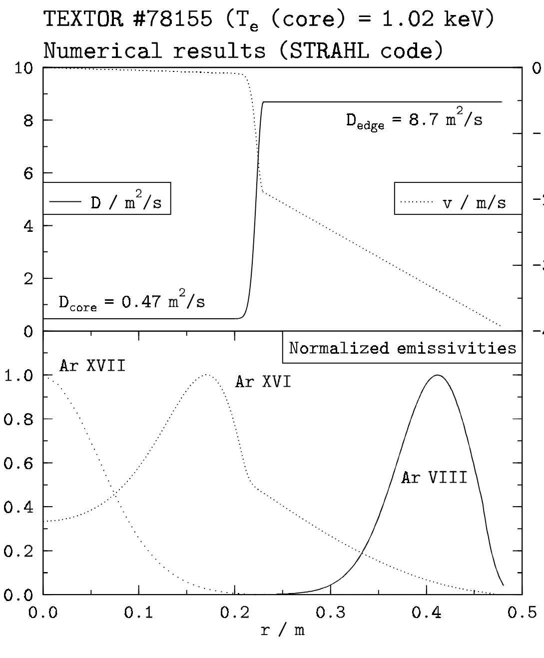

Figure 3: (upper graph) Radial profiles of diffusion coefficent D, radial drift velocity v of argon; (lower graph) argon emissivity profiles calculated by STRAHL

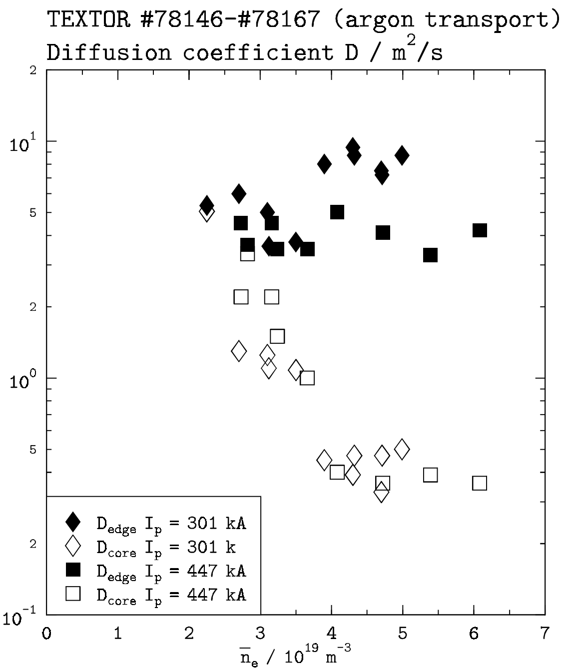

Figure 4: Experimental results evaluated by STRAHL calculations: diffusion coefficients for plasma edge and core at different mean densities and plasma currents