H/D RATIO CONTROL EXPERIMENTS
AT ASDEX-UPGRADE

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1. Introduction

In a fusion reactor maximum output power is achieved at a D/T isotope ratio of the plasma close to unity. Other T fractions may be desired in experiments as JET [1] and ITER [2], e.g. in order to keep the Tritium inventory low. Variations of the isotope ratio are to be expected, because plasma refuelling happens from various sources: From outside (gas puff, pellets or neutral beams) and from the first wall surfaces. The wall inventory is built up during time periods much longer than typical plasma time constants and limits the rate and amplitude of changes in the plasma composition.

2. H/D ratio determination

No direct method is available until now to measure the isotope ratio in the core of a large fusion plasma. Therefore one deduces information from mass spectrometry in the exhaust line, from the plasma edge or divertor H_α/D_α line intensities [3,4] and from neutral particle spectra [5]. The latter method can provide information from regions some 100 mm deep in the plasma, where the measured neutrals are emitted.

The conversion factor between neutral fluxes F and isotope densities n can be calculated with a neutral emission model. A wide range of plasma parameters and profile functions occuring in ASDEX-Upgrade were investigated [6]. The results were compared to experimental data of ohmic plasmas, where it is justified to assume maxwellian distribution functions and the same temperature for H^+ and D^+ ions. Here the neutral flux data have sufficient accuracy up to energies of about 6 KeV, corresponding to plasma radii greater than about 0.2 m. The assumption of a constant radial H/D ratio is compatible with the data, but some radial dependence cannot be ruled out completely. In the case of additional heating the fluxes are higher and extend to higher energies. Nevertheless the range of usable energies is even more restricted because of the presence of fast nonthermal particles. With NBI for example, generally energies up to 3.5 KeV are suitable. The following linear relation was found to hold in most cases of interest:

$$(n_H/n_D) = (F_H/F_D)/\gamma\,, \qquad \gamma = 1.55 \pm 15\%.$$

3. H/D ratio control experiments

The linear relation between isotope density and neutral fluxes is convenient for a feedback control system. A real time signal for the H/D ratio is formed from the outputs of appropriate

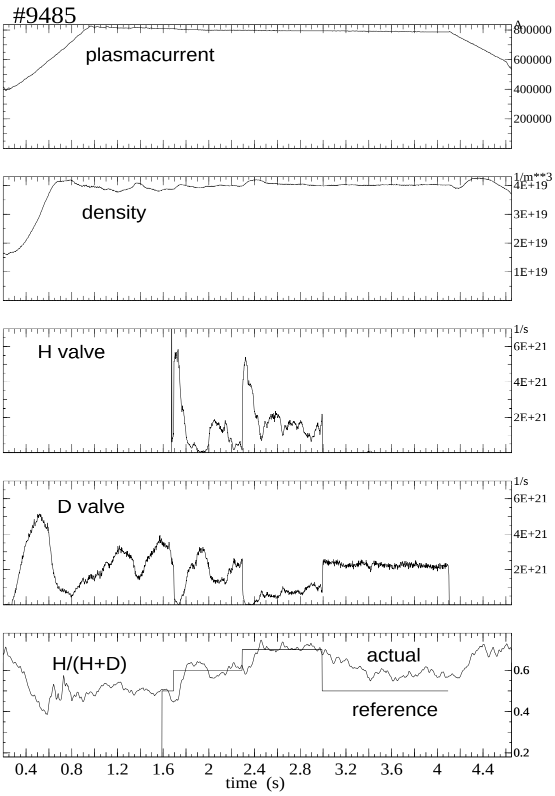

Figure 1. Ohmic discharge with the H/D ratio feedback controlled at times after 1.7 s.

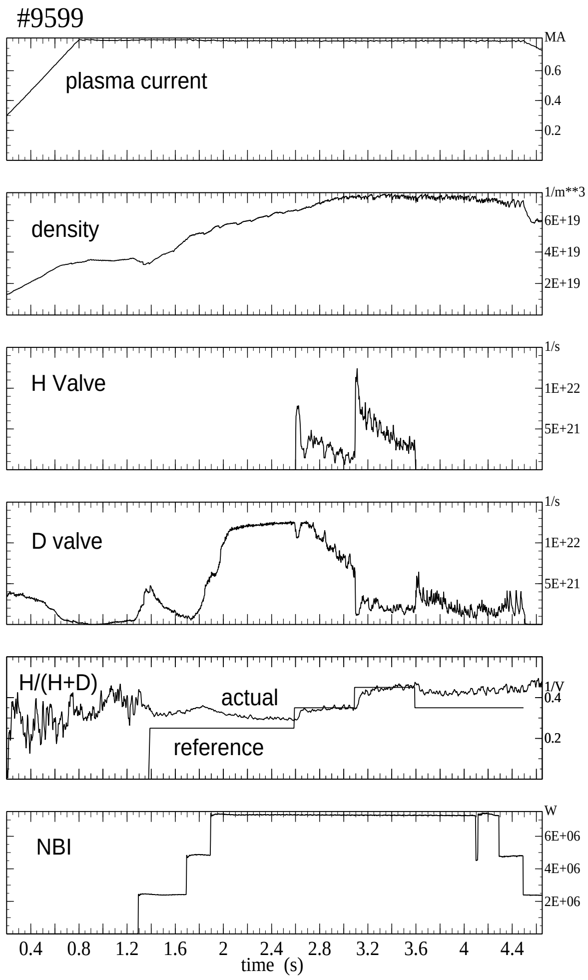

Figure 2: NBI heated discharge with H/D ratio feedback controlled at times after 2.6 s.

detectors of the Neutral Particle Analyzer [7] and serves as an additional input signal for the plasma density control system. The gas flux requested to control the density is split up between the H_2 and D_2 gas valves according to the requested ratio. The different channel sensitivity and the factor γ are compensated electronically. In Fig. 1 the results of an ohmic discharge are shown. The H fraction is near 0.5 in the first phase with pure D fuelling, when the H/D control system is not yet activated. The walls were still loaded with a large amout of H from an opening of the vessel a short time before. After 1.6 s, when roughly constant conditions were achieved, the reference variable is increased in two steps of 0.1. The H valve opens and the H/D ratio reaches the reference value within ≈ 0.1 s. Differences in the properties of the two valves lead to overshooting and slight density oscillations. When the reference variable is reset to the starting value, in both discharges the H valve closes immediately and the H fraction falls with time constants between 0.2 and 0.5 s, but the starting value is not reached in the remaining time before current ramp down. This can be explained by a lower fuelling gas flux in this phase and changes in the composition of the wall inventory during the discharge. Figure 2 shows a very similar behaviour for a discharge with Neutral Injection Heating.

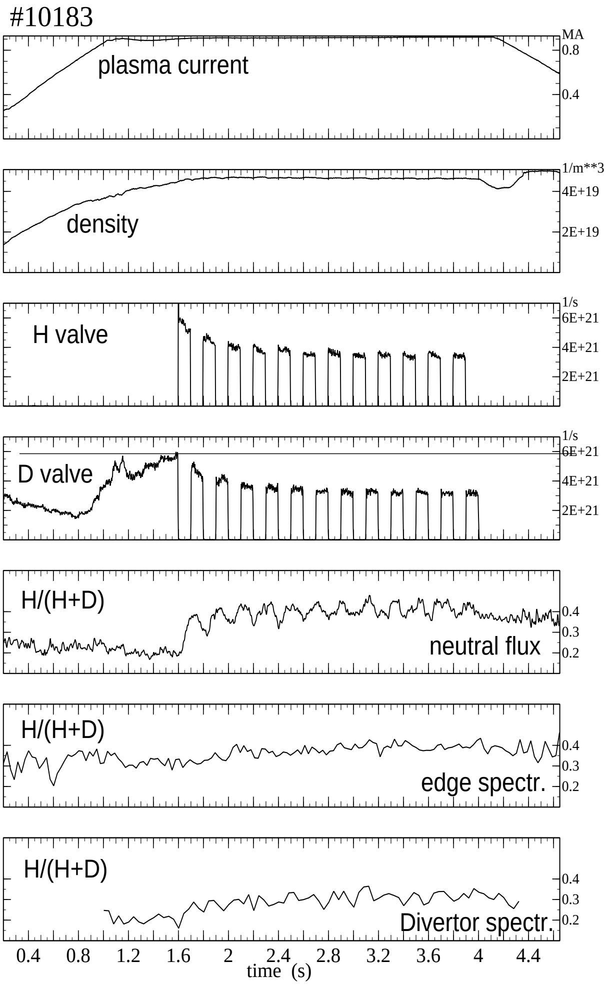

Figure 3. Ohmic discharge with alternate H and D Gas fuelling. The two lower curves show the H fraction from H_α/D_α line intensities in the plasma edge and the divertor.

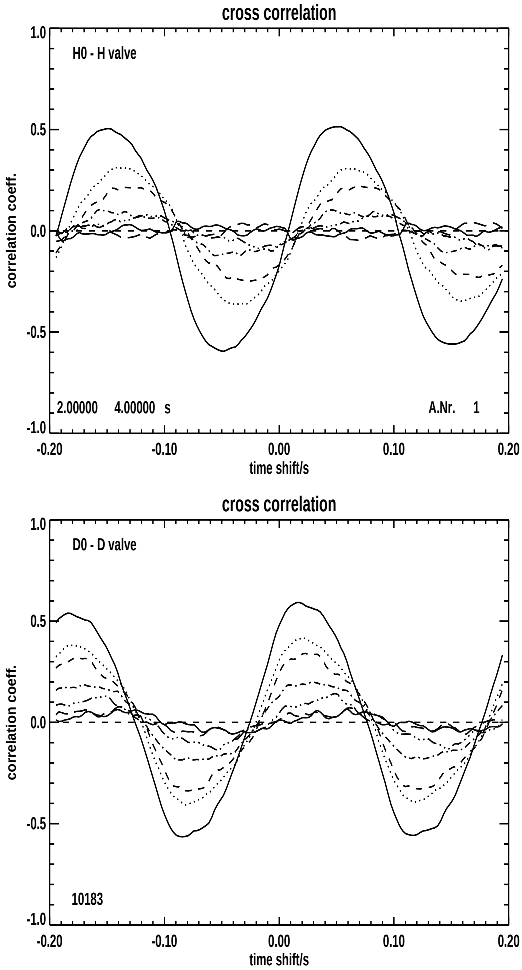

Figure 4. Cross correlation of H^0 and D^0 fluxes in respect to the H and D valve fluxes for various energies. The time delay increases, the correlation decreases with the energy of the neutrals.

4. Alternate H and D gas fuelling

In order to study the change of plasma composition in more detail alternate H and D gas pulses of the same size and 10 ms duration were applied to an ohmic discharge (Fig. 3). Effort was made to keep all other parameters as constant as possible, particularly the gas fuelling and the density, because these strongly influence the neutral fluxes. After two periods the H fraction oscillates rather regularly between 0.37 and 0.45. A correlation analysis shows a phase shift, which increases with the energy of the neutrals, at 5 KeV it is $\approx$ 30 ms (Fig. 4). If interpreted as propagation speed, it corresponds roughly to 10 m/s. This is consistent with the time delay of $\approx$ 200 ms between T fuelling and rising of the neutron rate, as observed at JET [8]. In view of the large uncertainties the data do not indicate any difference in the H and D behaviour.

Included in Fig. 3 are the traces of the H fraction deduced from H_α/D_α measurements in the plasma edge and the divertor. They measure the particle flux into the ionization zone and respond much less to the change of fuel gas, the edge spectrometer even less than the one in the divertor: The modulation amplitude is at least four times smaller, the mean stays at considerably lower values, and no step is present in the edge spectrometer signal at the time of the first H pulse. The relative locations in the torus are important for the different response of the three systems. The divertor spectrometer is located in the same section as the gas valves, which were used in these discharges. The plasma edge spectrometer is located about 90^0 away, where the influence of gas from the valve is strongly reduced. The neutral particle diagnostics is located at 90^0 in the other direction. As described above, it measures the H^+/D^+ ratio at a certain depth in the plasma and therefore can provide the actual plasma compostion. For long term variations in the order of characteristic times of the wall inventory the differences are reduced. This is shown by a comparison of the H/D ratio of about 400 consecutive discharges, covering two boronisations and one change from D gas to H gas fuelling. Only in the first few discharges after change of the fuelling gas there are large discrepancies, which indicate, that the composition of the wall neutrals, measured by the spectrometers, needs a few discharges to approach the composition of the plasma, measured by the neutral particle analyzer.

5. Conclusion

It has been shown, that control of the plasma isotope ratio based on measurements of neutral flux spectra is possible. A propagation speed of the order of 10 ms is estimated from the delay at different neutral energies. Variations of the isotope ratio could be produced intentionally with a response time less than 0.1 s and an amplitude of about ± 0.1 in our experimental conditions. Measurements of H_α/D_α in the plasma edge and the divertor reflect to a larger extent the recycling flux and the wall inventory. They respond less sensitive to fast variations in the fuel composition. In stationary conditions the H/D ratios of all three methods are in reasonable agreement.

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