PRODUCTION AND TRANSPORT OF IMPURITIES IN THE ASDEX TOKAMAK PLASMA

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ABSTRACT

The correlation of impurity fluxes and impurity densities in the plasma was studied in ASDEX for various elements and discharge parameters. The impurity confinement is well described by a diffusion transport model. With the influx of intrinsic impurities known, conclusions can be drawn on impurity sources and generation mechanisms.

1. INTRODUCTION AND METHOD

The impurity content of tokamak plasmas is measured quite routinely, but little is known about impurity fluxes due to plasma-wall interaction. However, a knowledge of these fluxes is very important for identifying the actual mechanisms and locations of impurity production. In ASDEX the correlation of the impurity density in the plasma and the respective impurity influx was studied in detail for different impurity species and experimental conditions. These are divertor (D) and toroidal limiter (tL) discharges in either H_2 or D_2, with or without neutral injection (N.I.). Since it is often difficult to measure the influx directly, the behavior of impurities was simulated by injecting gases, especially silane (SiH_4). Model calculations describing the measurements very well were also made.

In steady state, the total loss of impurity ions ϕ_i must be balanced by the total neutral influx ϕ_o. This outflux ϕ_i may be characterized by a particle confinement time, defined as $\tau_p = N_i/\phi_o$, where N_i means the total number of impurity ions in the plasma. In the context of a simple diffusion model /1/ the impurity ion flux can be calculated from an anomalous diffusion coefficient D_a and the gradient characterized by the ionization length of the neutrals, λ_{ion}. The particle confinement time is then

$$\tau_p = (\lambda_{ion} \cdot a)/2D_a.$$

λ_{ion} is a function of the neutral velocity v_o and the parameters of the edge plasma; D_a may be derived from transport studies of the plasma. The most accurate measurement in ASDEX by means of a neon-seeded pellet yielded

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$D_a \sim 4000\ cm^2/s$ for a deuterium and $D_a \sim 6000\ cm^2/s$ for a hydrogen background plasma.

A more sophisticated model must take into account the presence of parallel flows in the plasma scrape-off and of friction between impurities and the background ions. In the following, measured values of τ_p are compared with calculated values. The latter were obtained by a transport program using the following expression for the flux density of the impurity species i (Ref./2/):

$$\vec{\Gamma}_i = -(D_a \frac{\partial n_i}{\partial r} + 2\ \frac{D_a \cdot r}{a^2})\ e_r$$

with $D_a = 4000\ cm^2/s$. In the scrape-off region volume sinks are included to account for parallel transport. This program was also used for evaluating the impurity densities from measured radial profiles of individual spectral lines.

2. IMPURITY CONFINEMENT

2.1 Silane Injection

Silane was injected into ASDEX discharges to simulate wall-produced impurities. For this purpose a flux of about 10^{19} atom/s was puffed through a gas valve in the torus midplane. When this valve is opened, the radiation rises to a plateau value about 200 ms later. After the flux is switched off, the signals disappear. This shows that the processes of deposition and subsequent erosion of Si do not falsify the flux. τ_p can therefore be determined from the gas flux and the Si density in the plasma, as derived from absolute measurement of Si lines.

The results for different experimental conditions and background plasmas are summarized in Table 1. The code calculations in the last column assume that the neutral silicon penetrates the plasma edge at room temperature.

Table 1

			τ_p (ms)	
type	gas	$\bar{n}_e (10^{13} cm^{-3})$	exp.	calculation
divertor	D_2	4.4	1.8	1.8
divertor	H_2	4.4	1.6	1.8
tor. limiter	H_2	3.0	1.2	2.2
tor. limiter + N.I.	H_2	3.0	0.5	1.4

First the experimental results are discussed. A comparison of divertor H_2 and D_2 plasmas shows that the particle confinement times are very similar, though a different diffusion coefficient was previously found. The linear dependence on D_a is probably compensated somewhat by different properties of the H_2 and D_2 edge plasmas. Comparing the limiter and divertor cases, it turns out that the shielding properties of the two discharges are little different; in fact, the limiter boundary results in an even lower impurity confinement time. With neutral injection, τ_p is further reduced owing to a hotter edge plasma. The calculated values (with $D_a = 4000\ cm^2/s$ may be regarded as agreeing quite well with measurements considering the large uncertainties in the edge plasma parameters. For the N.I. case, an increase of

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The iron influx in divertor discharges can readily be explained by sputtering due to charge-exchange neutrals, even if the yield must be strongly reduced to account for surface conditions. This interpretation has already been adopted /4/ owing to the similar time behavior of the high-energy CX flux and Fe density in the plasma. Additional information may be derived from the transition of H_2 to D_2 plasmas. In ASDEX D-discharges a strong increase of the iron content has always been observed during this change of the working gas, while the amount of light impurities remains practically the same. As demonstrated by the silane results, the containment times in H_2 and D_2 are not much different. The higher metal contamination must therefore be due to a higher impurity influx in D_2 compared with H_2, a conclusion which is nicely confirmed by the collecting probe measurements in the divertor chamber. This dependence of the iron flux on the plasma background mass is a further indication of sputtering by CX neutrals.

Information on the oxygen sources is obtained by measuring the gaseous oxygen compounds in the divertor chamber. This indicates that oxygen must originate from the vessel walls at the beginning of the discharge, probably desorbed by low-energy H neutrals (necessary yield $\gtrsim 10^{-3}$). Later, a pressure of H_2O and CO builds up in the divertor chambers which is sufficiently high to explain the measured oxygen flux, i.e. oxygen is just recycling. According to the measurements it is obvious that the vessel walls can build up a few monolayers of water between successive shots. The effective long-term decrease of O is therefore very slow and is determined by the speed of the turbopumps.

The behavior of divertor-produced metallic impurities is still being studied, but is complicated by the fact that the vessel walls are also covered with these materials.

4. DEPOSITION OF MATERIAL ON WALLS AND WINDOWS

ASDEX H_α windows have been regularly analyzed with respect to deposited metals. Layer thicknesses of up to 1 µm and up to 10^4 droplets per mm^2 have been found, the result being strongly correlated with the position of the poloidal limiter /5/. The amount of transported material in this case is much too high to be explained by the above fluxes during discharges and the integrated discharge times. This transport must be due to other processes such as electric arcs, droplets or flakes falling onto the plasma, or occasional melting of the limiter due to local power overload.

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