Erosion of the main chamber walls of Tokamaks by CX-neutrals

H.Verbeek, J.Stober, D.P.Coster, and R.Schneider

Max-Planck Institut für Plasmaphysik, EURATOM Association,
D–85740 Garching, Germany

Introduction

Investigations on wall erosion have been widely concentrated on the divertors of plasma machines. However, the erosion in the main chamber and the transition region needs still to be considered, because of the limited lifetime of the wall and impurity influxes to the plasma.[1] The aim of this paper is to assess the parameters and conditions which influence the erosion of the walls.

The CX-spectra

At ASDEX Upgrade the CX fluxes and energy distributions have routinely been measured in the energy range of 20 to 1000 eV by the Low Energy Neutral particle Analyzer (LENA)[2] at one particular location at the outside wall. Its line of sight and that of an H_α monitor is horizontally, slightly above the midplane. The CX intensities and the shapes of the corresponding energy distributions, which can be characterized by the total fluxes and the mean energies (E_{mean}) depend largely on the discharge conditions. For constant heating power E_{mean} decreases when n_e is raised while the flux increases [3],[4]. As an example the CX-spectra in a NI heated Deuterium discharge at different n_e are shown in Fig.1. For discharges with auxiliary heating the flux increases usually with the heating power but E_{mean} shows no simple dependence. The CX intensity is roughly proportional to the local neutral gas density, which depends on the nearby recycling sources and external gas puffs, while E_{mean} depends on the edge plasma parameters.

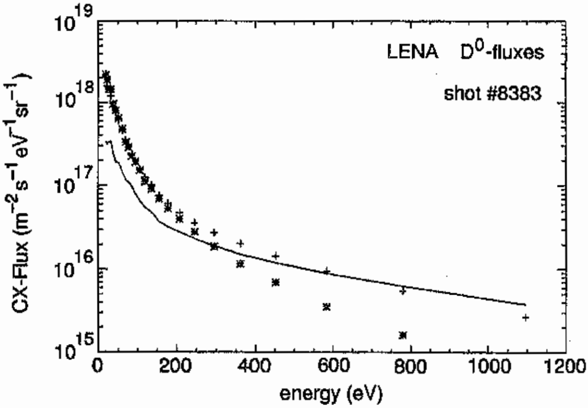

Figure 1 *shot #8383 with density ramp-up:*
(——) n_e=7.0×$10^{19}m^{-3}$
(+++) n_e=8.4×$10^{19}m^{-3}$
(***) n_e=9.7×$10^{19}m^{-3}$
Gas D_2, P_{NI}=7.9 *MW*,

For the determination of the CX wall-erosion at the location of the LENA the measured CX spectra have to be multiplied by the energy dependent sputtering yields Y(E). However, the spectra have to be extended to lower energies (down to 1 eV) in the case of Carbon walls, where chemical sputtering is important, and to higher energies if walls of other materials are considered (the maximum of the sputtering yield for D on W e.g. is at 5 keV).The latter is possible from the measurements of the high energy CX-diagnostic, whose spectra overlap nicely with those of LENA. The extension to lower energies is based on polynomial fits to the experimental data. For one particular shot (#7649, D_2 with I_p=1 MA, P_{NI}=5.2 MW, $n_e=9\times10^{19}$ m^{-3}),the procedure has been checked with flux simulations obtained from the T_i determination by EIRENE simulation [5], assuming an exponential decay of T_i in the SOL.

LENA measures the CX flux in a line of sight almost perpendicular to the separatrix. The wall is, however, seen by particles from the whole half space. Therefore the angular distribution of the CX neutrals has to be known. For shot #7649 (s.above) the spectra for lines of sight at angels 20, 40, 60, and 80 deg to the normal were calculated from the Eirene simulation. From these the angle integrated spectrum was determined. This had a very similar shape as compared to the LENA-spectrum. Therefore this could be taken into account merely by a factor.

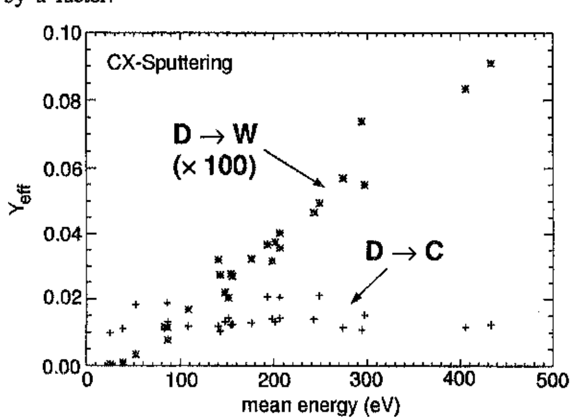

Figure 2 *Effective erosion yields Y_{eff} of C (+++) and W (***) ×100 for 26 randomly chosen ASDEX Upgrade shots*

Sputtering

For the erosion of Carbon walls the formula of Roth and G.-Rosales [6] was applied. This includes temperature and flux dependences. For the consideration of other possible wall materials also W, Be, SiC, TiC and WC were investigated. The corresponding sputtering yields were calculated by the Bohdansky formula and the data of Eckstein et al.[7]. The effective sputtering yields Y_{eff} were determined by multiplying the CX-spectra with the corresponding Y(E) , integration over all energies and normalization to the total CX-fluxes.

For a randomly taken number of shots with and without NI and a wide range of densities Y_{eff} was determined. It turns out that Y_{eff} rises monotonicly with E_{mean}. As an example Y_{eff} for W and C at 300K are shown in Fig.2. No points were omitted, and thus Fig.2 seems to be fairly universal. For the considered shots Y_{eff} for W increases by a factor of 50, while for C it varies only by a factor of 2 and for Be by a factor of 2.5. Y_{eff} for the other materials increases likewise with E_{mean}. This is due to the fact that the sputtering yield for W has a threshold energy for D of 178 eV while it is 26.2 eV for Be and of 1 eV for C because of the chemical effects. For the metals the dependence of Y(E) form the angle of incidence[7] could be taken into account using the above mentioned calculated spectra for different angles. This enhanced Y_{eff} by a factor of 2 for W and Be, but it is questionable, whether this applies since the walls have not at all atomically flat surfaces.

Toroidal and poloidal effects

Though LENA is located at a place where no strong neutral gas sources are nearby it is difficult to estimate the wall erosion and the impurity influx to the entire machine from one local measurement since the CX fluxes vary strongly toroidally and poloidally.

Toroidal variations are mainly due to the differences in local neutral gas sources, recycling at protruding parts and external gas puffs. For ASDEX-Upgrade these variations have not be determined quantitativly so far.

To account for the poloidal effects the CX energy-distributions were modelled by B2–EIRENE calculations [8]. These give a selfconsistent calculation of the plasma taking into account the full geometry of ASDEX-Upgrade. Here we discuss the particular shot #7888 (H_2 with P_{NI} = 5MW with ramped-up density) at the 2 timepoints when the seperatrix-density n_e^{sep} is =3.2 and = 5.2×10^{19} m^{-3}. At the 1st timepoint the plasma was attached, at the 2nd fully detached. To achieve a good match between the simulation and the CX- and H_α measurements the T_i profile and the neutral sources in the main chamber had to be adjusted.

The necessary reduction of T_i in the outer SOL indicates that the diffusion coefficients used for modelling are not adequate for this outer layer, possibly due to flute mode driven anomalous transport [9]. The neutral source strength in the main chamber along the outer contour had to be shifted from the outside to the inside to keep the correct value of the experimental H_α intensity and to match the measured CX intensities. (B2–Eirene uses local recycling along the outer contour but in reality it is concentrated at the inner heatshield.) Since the main chamber source strength is only 1/100 of the divertor source this does not disturb significantly the self-consistency.

For the Monte Carlo calculation grid (the outermost contourline of which is shown in Fig. 3A) 216 lines of sight perpendicular to the outer SOL-contour were constructed and the associated CX-spectra were calculated as a first step. At the LENA location they agree fairly with the experimental CX spectra. The CX-flux distributions along the poloidal circumference are very different for the 2 cases, and in both vary the fluxes poloidally by up to 3 orders of magnitude and E_{mean} by a factor of 50.

From the spectra the total erosion yields Y_{tot} were calculated for different wall materials. The resulting Y_{tot} along the SOL-contourline are shown in Figs. 3B and 3C for carbon (at 300K) and tungsten walls for the 2 timepoints. Y_{tot} for W is multiplied by 430 because the tolerable concentration of an impurity considering radiation and dilution is for W ca. 1/430 than that for C [10]. It should be noted, that just above the divertor, the present choice of the lines of sight perpendicular to the contour is not sufficient to account for angular effects in this region. Neutral atom fluxes at the target plates are mainly due to dissociation of desorbed molecules which are not included in the CX spectra.

Conclusions

CX-sputtering in the main chamber occurs at different places for C or W walls for both low and high density. W sputtering is most severe in the main chamber while it is low in the transition region because E_{mean} is sufficiently high only in the main chamber. The minimum at the top of the machine for all materials is due to the low neutral gas density there. This is important for a proper material choice in future machines.

The W-flux is much lower at 2.45 s than at 1.75 s due to an increased density in the cold SOL which absorbs the hot neutrals coming from the central plasma, thereby reducing E_{mean}. C sputtering is increased almost everywhere since the chemical sputtering does not depend strongly on T_e but on the integral neutral flux (except target plates, where T_e is too low in the detached case). Considering plasma impurities it can be concluded that W would be a favorite wall material in the detached case, whereas C would be favorable in the low

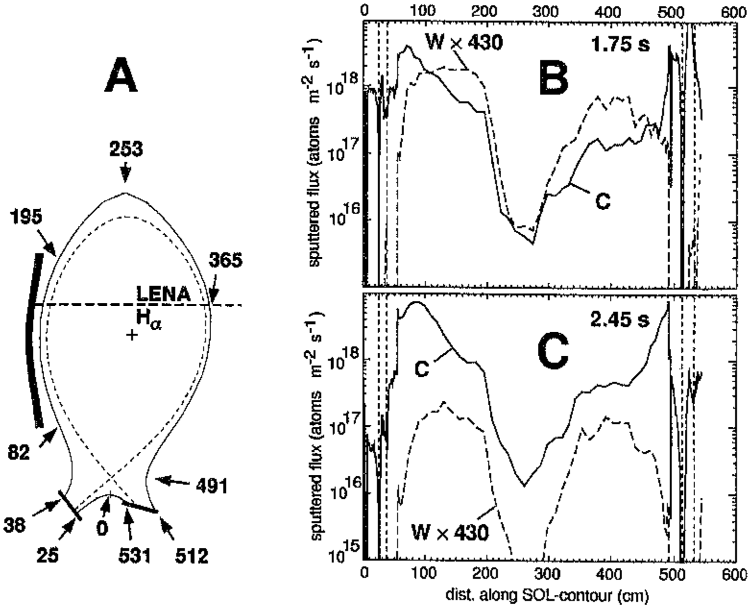

Figure 3 **A:** *The outermost contour and separatrix of the grid for the B2-EIRENE calculation. Divertor plates and inner heat shield are indicated. The distance along the contour is given in cm.* **B:** *Sputtered flux of C and W (dashed ×430) for #7888 along the SOL-contour at 1.75s (low density) and* **C:** *at 2.45s (high density,detached) . The vertical dotted lines in* **B, C** *indicate the position of the divertor plates.*

density case assuming that sputtered C and W atoms have the same probability to penetrate the plasma . Differences of the penetration behaviour for W and C are still under investigation. A favorable effect for W is the higher rate of prompt redeposition, which is estimated to be roughly 50 % (C < 10 %)[11].

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