RADIAL AND POLOIDAL DISTRIBUTION OF IMPURITIES AND DEUTERIUM DEPOSITED ON THE FT LIMITER DURING OHMIC DISCHARGES

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INTRODUCTION

In a machine with limiter operation, such as the Frascati Tokamak (FT), the limiter is the main source of foreign atoms affecting the plasma purity and makes a large contribution to the total recycling of the working gas [1]. In turn the surface composition and topography of the limiter are changed, erosion-redeposition phenomena taking place because of the plasma flux. The knowledge of the radial and poloidal distributions of impurities and deuterium deposited on the limiter can be of great importance for understanding the complex plasma-limiter interaction, particularly with regard to the observed asymmetries of the scrape-off parameters [2].

In this work the stainless steel full poloidal limiter of FT [3] was equipped with six graphite targets in order to study the spatial distributions of impurities and deuterium within larger radial and poloidal ranges with respect to previous investigations [4,5].

EXPERIMENT

Three 15×10×2 mm^3 graphite (grade EK98, Ringsdorff) targets were mounted on the ion side and three on the electron side of the stainless steel limiter support and poloidally distributed all around the limiter circumference, as shown in Fig. 1.

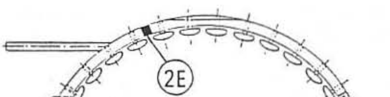

Fig. 1: Schematic view of the main poloidal FT limiter showing the position of graphite targets.

The collecting surfaces of the targets were oriented perpendicularly to the toroidal magnetic field. The reliable measurement point closest to the plasma edge was at r-a = 1.3 cm, where a = 20 cm is the plasma radius.

All the targets but one were exposed to 623 ohmic discharges in the April/May 1986 experimental period; once, when the limiter was temporarily extracted after 494 shots, the target mounted on the bottom ion side (1I in Fig. 1) was removed. The main plasma parameters were I_p = 300÷600 kA, B_T = 6÷8 T, $\bar{n}_e$ 0.7÷2.7×10^{14} cm^{-3}. The toroidal field was parallel to the plasma current. After removal from the limiter the targets were surface analysed by SEM, PIXE and NRA.

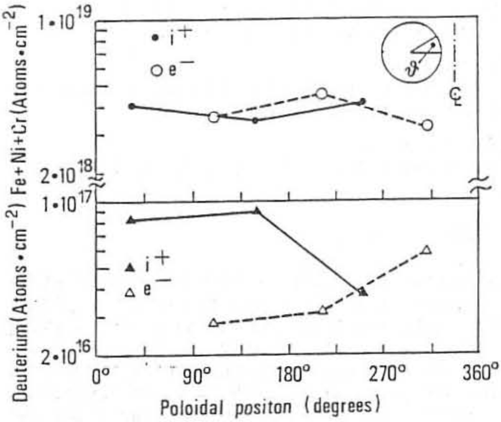

Fig. 2: Radially averaged poloidal distribution of metal and deuterium deposited on the graphite targets.

RESULTS

Metal Deposit Analysis - The metal coverage (Fe+Cr+Ni), averaged over the seven experimental points radially measured by PIXE on each of the six graphite targets, was found to be $3\div5\times10^{18}$ atoms cm^{-2} (more than a thousand monolayers) with no large poloidal or directional (electron vs ion side) differences (Fig. 2).

The chromium concentration on all the targets was about twice as large as in the stainless steel used as limiter (AISI 316) and wall (AISI 304) material. The target subjected to fewer discharges than the other ones showed the same amount of metal deposit.

With respect to the radial distribution of metallic impurities, a concentration continuously decreasing with the distance from the plasma edge was found in the inner part of the limiter on the electron side (target 3E), with an e-folding length of ~ 1 cm, and, less clearly, on the ion side (Fig. 3). In the other parts of the limiter the radial distribution was almost uniform, with a smooth maximum at intermediate positions between the top and bottom of the targets.

Deuterium Analysis - Higher radially averaged deuterium concentrations were measured on the ion side ($8\div9\times10^{16}$ atoms cm^{-2}) than on the electron side (~ 3×10^{16} atoms cm^{-2}) by the $D(^3He, p)^4He$ nuclear reaction on the targets which had been subjected to an equal number of discharges and showed similar impurity distributions (Fig. 2).

Unlike metallic impurities, lower D concentration by a factor 2÷3 was found on the target 1I with respect to the other targets facing the ion side.

The radial distribution was rather uniform (Fig. 3), with shallow maxima and minima occurring at different positions, but the target 4E showed a D concentration clearly increasing with the distance from the plasma.

DISCUSSION

The general pattern observed in the metal deposit (as well as in the deuterium concentration) is the result of several hundred both normal and disruptive discharges. The evaluation of impurity fluxes in the scrape-off from the measured concentrations is to be carefully considered because of the different impurity amounts released in such a large number of discharges.

Erosion action of the plasma and nonlinear dependence of the deposit thickness on the number of discharges can also lead to misleading results.

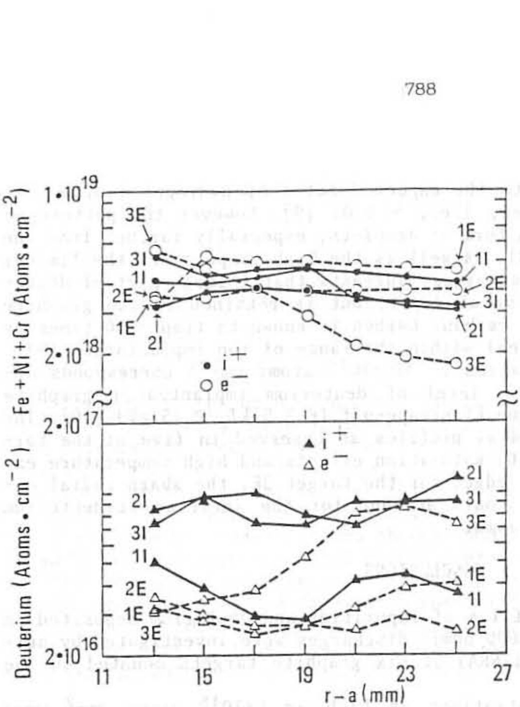

Fig. 3: Metal and deuterium concentration on the graphite targets as a function of the radial distance from the plasma. See Fig. 1 for the poloidal position of the different targets.

In effect a nonlinear dependence is inferred by comparing target 1I with the other ones.

Moreover the metallic impurities collected by deposition probes mounted on the limiter sides are largely the result of local redeposition close to the erosion area.

According to the measured values of density and temperature in the FT scrape-off [6] ($\tilde{n}_e \sim 1\times10^{12}$ cm^{-3}, $T_e \cong 15$ eV at 1÷2 cm outside the plasma edge) and the calculated ionization rate coefficients (i.e. $<\sigma v> \sim 1\times10^{-7}$ cm^3 s^{-1} for a Cr atom [7]), a particle sputtered from the limiter side with an energy of a few eV has a mean free path for electron impact ionization as short as ~ 1 cm. Therefore it has a high probability of being ionized and of returning to the limiter under the combined action of the friction with the background plasma and the acceleration by a pre-sheath electric field. Atoms released with thermal energies by evaporation have an even higher probability of redeposition owing to their shorter ionization mean free path. Therefore the large Cr/(Fe+Ni+Cr) ratio observed on all the targets is probably due to preferential Cr evaporation from the neighbouring hot zones of the limiter.

The decrease of metal deposition with increasing distance from the plasma as found on the inner targets (especially on the electron side) could be related to a poloidally asymmetric radial profile of energy flux to the limiter. A minimum density (and energy) e-folding length has been found in the inner part of the poloidal cross section of Alcator-C by Langmuir probes [2].

Particle and energy fluxes concentrated on the upper part of the elliptically shaped mushrooms (see Fig. 1) cause a release of metal atoms minly directed onto closed flux surfaces inside the limiter radius [8].

On the other hand, longer energy and particle e-folding lengths cause the release of metal impurities which are ionized in the scrape-off and directly collected by the limiter and overlap the impurity outflux from the main plasma. The result could be a nearly constant deposit as observed on the targets apart from those on the inside of the poloidal cross section.

With respect to the working gas concentrations, the deuterium implanted in the targets within ~ 1 μ from the surface (the depth range of NRA ana lysis) seems to correspond to the expected ratio of hydrogen isotopes to host atoms in stainless steel, i.e., ~ 0.01 [9]. However the pattern of metal deposition, which is in form of droplets, especially farther from the plasma edge (as found by SEM), as well as the high temperature the limiter surface reachs during the discharges, suggests that a large part of deuterium is not trapped in the metal layer, but is retained in the graphite substrate or in co-deposited carbon. Carbon is known to trap ~ 40 times as much hydrogen as stainless steel within the range of ion implantation [9].

The measured D concentration (~ $3\div9\times10^{16}$ atoms cm^{-2}) corresponds approximately to the saturation level of deuterium implanted in graphite with the energy expected in the FT scrape-off ($E \cong 5\ kT_e \cong 75$ eV) [10]. The flatness of the deuterium radial profiles as observed in five of the targets could be ascribed to both saturation effects and high temperature excursions close to the plasma edge. For the target 3E, the sharp radial decrease of the metal deposit could account for the increase of deuterium with the distance from the plasma.

CONCLUSIONS

Radial and poloidal profiles of impurities and deuterium deposited on the FT limiter during about 600 ohmic discharges were investigated by surface analyses (SEM, PIXE and NRA) of six graphite targets mounted on the SS limiter support.

Metal (Fe+Cr+Ni) concentrations as high as 5×10^{18} atoms cm^{-2} were found with no large poloidal or directional differences. The chromium concentration was twice as large as in stainless steel, probably due to preferential evaporation from the limiter.

The radial profile of impurities was rather flat apart from on the inside of the poloidal cross section, especially on the electron side ($\lambda_{Fe+Ni+Cr}$ ~ 1 cm), perhaps as a result of asymmetry in the density and energy scrape-off lengths.

The overall deuterium concentration was higher on the ion ($8\div9\times10^{16}$ atoms cm^{-2}) than on the electron side (~ 3×10^{16} atoms cm^{-2}) and poloidally uniform.

The radial deuterium distribution did not exhibit any decay with the distance from the plasma.

Further analyses on a new set of targets mounted on a limiter with INCONEL mushrooms are in progress.

FOOTNOTE AND REFERENCES

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