CARBON EROSION AND DEPOSITION AT THE JET LIMITERS

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INTRODUCTION

Carbon is the major impurity in the JET plasma, and may limit the ultimate temperatures and densities obtained. To understand the carbon levels observed it is important to assess the production mechanisms at the limiters and walls, and transport in the plasma. This paper describes studies of carbon erosion and deposition at the carbon limiters in JET in 1986, performed by marker experiments. The pattern of erosion from and deposition observed on the limiters represent a starting point for impurity transport calculations and are also important for predictions about erosion in future plasma machines with higher temperatures and larger pulses.

EXPERIMENTAL

Before the 1986 operations a carbon limiter tile was implanted with ^{13}C at 1.4 MeV to a mean depth of ~ 2 μm at a number of points on the surface facing the plasma. The shape of the limiter tile was also accurately measured using a coordinate measuring machine to show up larger changes in dimensions (>a few microns). The limiter tile was placed adjacent to the plasma midplane on the limiter in octant 1D. Altogether there were eight limiters in operation for almost all 3200 discharges of the 1986 campaign, the limiters being effectively 12mm in front of the protection tiles of the three RF antennae.

While the investigation of limiter erosion can only give a global result after many discharges, erosion in one discharge was also investigated with a special limiter probe which was also implanted with ^{13}C, however at 40keV (0.1μm mean depth). The limiter probe was a 50mm diameter cylinder of POCO graphite mounted on one of the manipulators of the Fast Transfer System (FTS) which allows samples to be inserted into the shadow of the limiters just above the outer midplane of the vessel (in Octant 7) (Fig.1a). From this position, the probe has a short connection length on the electron drift side of ~2.5m to a graphite limiter in octant 6D, whilst on its ion-drift side it has a long connection length of either ~25m to the inner wall or ~55m to a limiter, depending on the size of the plasma.

After exposure the limiter tile and the probe were analysed by Secondary Ion Mass Spectroscopy (SIMS) to determine the depth of the ^{13}C marker.

In addition nuclear reaction techniques were used to measure deuterium, and Rutherford Backscattering (RBS) and Proton Induced X-ray Emission (PIXE) were used to determine metallic deposits.

RESULTS AND DISCUSSION

On the limiter tile the ^{13}C marker had disappeared in the central part, while it could still be detected on the edges. On the ion drift side ^{13}C was discovered 22μm beneath the surface, being covered by a deposited layer of ^{12}C containing of the order of 0.5% Ni impurity and several per cent of hydrogen isotopes (5% H, 1% D). On the electron drift side even heavier deposition was observed with some flaking of the deposit: flake thicknesses were about 100μm. This is consistent with the physical measurement of the limiter tile (Fig.2). It shows that over the central region of the tile erosion of over 200μm occurred. Fig.2 includes the results from three scans across the tile, each of which gives a similar profile. Three tiles of another limiter have also been measured yielding similar depths of erosion. Computer calculations of erosion and redeposition on limiter surfaces predict large erosion and redeposition (). However, the net changes appear to be small, so that the 200 μm observed here may only be a small fraction of the total erosion.

The erosion of the limiter tile is the result of about 3200 discharges including many different modes of operation and other events such as glow discharge cleaning and disruptions. In order to determine the erosion and deposition during a well-defined discharge the special probe was exposed using the FTS. The probe was inserted to within 10mm of the last closed surface for two identical 5MA shots with 5 secs flat tops: a section of this limiter probe is shown in Fig. 1b. The surface at all points on the section of the probe marked in Fig. 1b with circles was analysed for D, Ni and Cr by nuclear techniques, and points also marked with squares were profiled with Secondary Ion Mass Spectroscopy (SIMS) to look for the ^{13}C marker, and study the depth distribution of other elements. The probe shows a similar erosion pattern to that at the main limiter. At points furthest from the plasma the marker was present at a depth larger than prior to exposure, while nearer the plasma

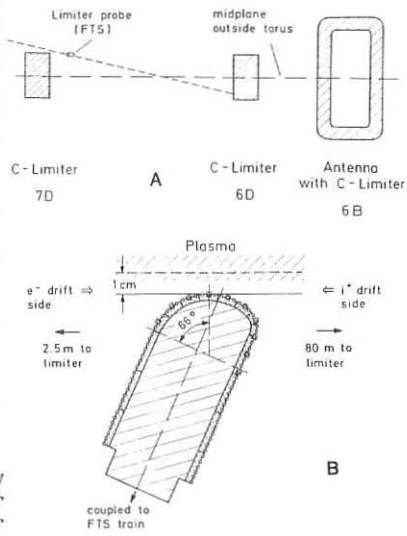

Fig. 1(a) Relative positions of components in the JET vessel.
(b) Geometry of the limiter probe.

the markers could not be detected. However, at the surface tangential to the field lines ^{13}C was detected but in a somewhat modified distribution. Fig.3 shows the results of the nuclear analyses of the probe. For each analysis point the areal elemental concentration is plotted against the distance from the plasma, taking into account the angle between the surface normal and magnetic field lines. Large fluences of deuterium are observed of up to 10^{18} atoms cm^{-2}, disregarding the anomaly at the centre which is due to the angle correction. The Ni and Cr are plasma impurities and on the ion side are in total about 0.5% of the collected deuterium. The amounts collected on the electron-drift side are considerably less, probably due to the shorter connection length. From the large amount of D observed even in the eroded regions it has to be assumed that after erosion, codeposition of carbon and deuterium plus hydrogen occurred in a later phase of the discharge. A trapped D fluence of 8×10^{17} atoms cm^{-2} cannot be due to ion implantation ([2]) at a plasma edge temperature of about 100-200 eV ([3]), but indicates a deposited layer of about 0.2 µm of saturated carbon ([4]).

CONCLUSIONS

The JET limiters show both large amounts of erosion and deposition, according to the proximity to the plasma. Close to the plasma ~ 200 µm have been eroded in 1986, corresponding to about 60 nm (net) per discharge, whilst a few centimetres from the plasma up to 100 µm nas been deposited onto the original surface: this is the cumulative result of exposure throughout the 1986 campaign.

The limiter probe was exposed to just two identical 5 MA discharges to show what happens at the limiter on a much shorter timescale. It is found that erosion and deposition patterns are very similar to the main limiters in that erosion of > 0.1 µm occurs near the plasma edge, and deposition occurs a few centimeters away from the edge. However, there is also as much deposition on the surface in the eroded zone as elsewhere: this must occur in a later part of the discharge. It is therefore necessary to investigate this on a smaller time scale, so that one can ascertain within a single discharge when erosion and deposition occur.

Globally, one finds that most of the carbon from the limiters (and from the inner wall) is deposited on the sides of the limiters and on the RF antennae, whilst a relatively thin layer of carbon (with some co-deposited D and H, and a low concentration of metals) covers the vessel walls. This layer was not maintained on the inner half of the vessel in 1985, and carbonisation was found to reduce the metallic impurities in the plasma. However, the thin layer of carbon on the vessel wall in 1986 may simulate an all-carbon wall in JET, explaining the low metal concentrations found in the plasma.

ACKNOWLEDGEMENTS

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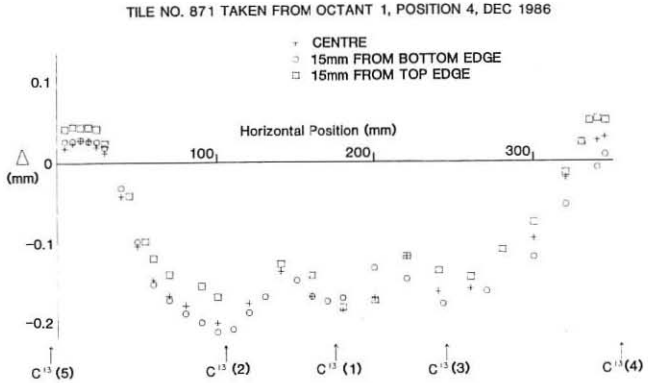

Fig. 2 Topographical changes in a limiter tile after use in 1986.

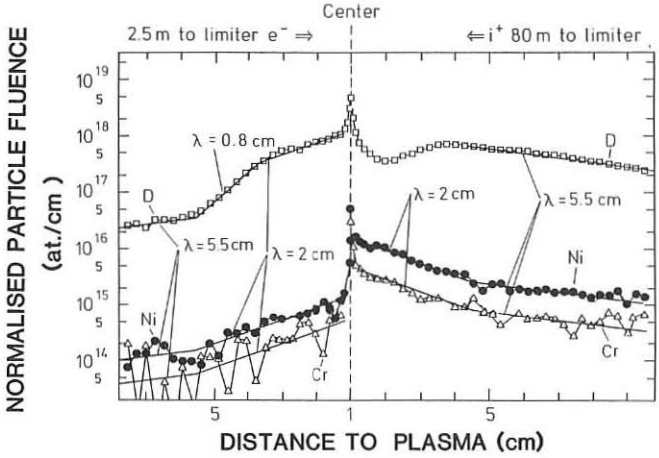

Fig. 3 Nuclear analysis of the limiter probe.