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SAND-79-1656C
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FLUX AND ENERGY OF DEUTERIUM INCIDENT ON A LIMITER-LIKE PROBE IN PLT

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ABSTRACT

The radial dependence of the flux and energy of deuterium incident on a probe in PLT has been determined from analysis of deuterium retained in the probe. From this data and the assumption of a poloidal symmetry we conclude that deuterium ion impacts on the limiters can account for an impurity generation rate via sputtering of $.5 - 3 \times 10^{19} \text{ s}^{-1}$ and a power flow onto the limiters of 11-18% of the ohmic heating.

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Introduction: The energy distribution of ions and neutrals striking surfaces of the tokamak vacuum chamber are important parameters in the overall power balance and impurity generation processes. Furthermore, the energies of the hydrogenic particles determine the saturation level of hydrogen isotopes in the walls and hence the tritium inventory in DT devices. Data on the energy distribution are available for neutrals at high energies from stripping cell analyzers, but there is little data on ions or low energy neutrals. The energies of ions cannot simply be deduced from plasma parameters as the ion energy may be modified by sheath potentials before striking the wall. New techniques for measuring the energy of hydrogen isotopes have been proposed based on depth distribution and saturation trapping value of the ions implanted in carbon and silicon collectors [1]. Some experimental results have been reported for TFR [2] and PLT [3]. The present paper reports the energy and fluence of deuterium as a function of radial position and evaluates the role of these particles in power balance and impurity generation.

Experiment. A set of carbon and silicon samples were mounted in PLT on a grounded, rotatable cylindrical probe behind a shield which had 3 mm slits on both the ion and electron drift sides, (Fig. 1). The samples were positioned on the torus mid-plane, with those nearest the plasma being just at the position of the outside limiter (45 cm). Those furthest from the plasma were behind the nominal wall position (50 cm). The plasma radius was determined by top and bottom carbon mushroom limiters at $r = r_0 = 40$ cm. The horizontal position of the plasma center was feedback stabilized at $R = 137 \pm 2$ cm (Fig. 1). A series of exposures were made on each set of samples by rotating the cylinder. The exposures were to 1, 2, 3, 6 and 12 low density discharges typical of those used for ICRF heating, i.e. $I = 230$ kA, $\bar{n} = 0.9 \times 10^{13} \text{ cm}^{-3}$, $T_e(0) = 1.1$ keV, $B = 17$ kG, $V_e = 2.6$ V, and the pulse length was 0.4 sec. No auxiliary heating was applied during the present exposures. After exposure to the plasma, the samples were removed and analysed using

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both secondary ion mass spectrometry and $^3\text{He} (d,p) ^4\text{He}$ nuclear reaction analysis [3] for the amount of deuterium retained as function of the number of discharges. From this data and using the theoretical model [1], the mean energy, $\bar{E}$, and flux, Γ , of the incident ions were obtained under the assumption of a Maxwellian energy distribution. The depth profiles indicate that the ions have a broad energy distribution. The saturation behavior of the trapped deuterium as a function of incident flux gives another indication that the flux is not mono-energetic. [4] But because of the uncertainty about the detailed energy distribution we will refer to a mean energy for the deuterium rather than a temperature.

Results. The incident flux is determined from the absolute amount of retained deuterium after corrections for reflection and saturation. Figure 2 shows fluxes calculated for both $\cos \theta$ and normal incidence impact angle distributions. The flux falls off monotonically with radius. At radii greater than 50 cm, in a recess in the vacuum wall, the flux drops by more than an order of magnitude. A low flux in this region is expected due to charge exchange neutrals, some being backscattered from the walls.

The results for the mean ion energies obtained as a function of radial position are shown in Fig. 3. In the range of the data, the energies are insensitive to whether a normal incidence or $\cos \theta$ distribution is chosen. The energies and fluxes on the electron drift side are consistently below those on the ion drift side. Electron temperature profiles were not measured during the discharges which were used for sample exposure, but results obtained from Thompson scattering in similar discharges at a later date indicate values of T_e of 180 ± 50 eV at $r = 36$ cm [5]. If T_e were still above 100 eV at $r = 45$ cm and a sheath potential $-3T_e$ developed at the surface, then the sheath would have contributed a large fraction of the total energy.

Discussion. The high energies, although initially surprising, are only two times higher than energies observed in the divertor of the relatively cool C stellarator [6]. The power flux is calculated from the ion flux and mean energy and equals $\frac{4}{3} \Gamma \bar{E}$. We have also included the angle of the probe with respect to the toroidal field. The power falls off exponentially with an e-folding distance of 2.4 cm (Fig. 4). Integrating over the radius from 45 cm to 51 cm and over 2π in poloidal angle gives the total power flow in this annulus of

40 to 100 kW. The lower end of this range corresponds to normal incidence impact as would occur if a large sheath were present. The upper end corresponds to a $\cos \theta$ distribution of impact angles. Over half the power is lost between 45 and 47 cm.

Making an integration over the same area for the sputtering due to these ions and using Bohdansky's sputtering yields [7], we obtain an erosion rate of $0.6 - 1.5 \times 10^{19}$ atoms s^{-1} for stainless steel, and $1.2 - 3.0 \times 10^{19}$ atoms s^{-1} for carbon. If the impurities were uniformly distributed through the plasma, this would be equivalent to an injection rate of $1.3 - 3.5 \times 10^{12}$ and $2.6 - 7.0 \times 10^{12}$ atoms $cm^{-3} s^{-1}$ for Fe and C respectively. Again, more than half the yield comes from the annular region between 45 cm and 47 cm, the location of the PLT stainless steel ring limiter.

If we assume that deuterium arriving at the ion side target at $r = 51.6$ cm is representative of the charge exchange outflux, then integrating over the whole torus wall gives an estimated charge exchange rate of 10^{21} deuterons s^{-1} . This would produce sputtering comparable to that of the charged particle flux to the limiter. Such an extrapolation is, however, hazardous as the poloidal and toroidal asymmetries are known to be large.

Conclusion. The use of surface probes in the plasma edge has provided information about the flux and energy of particles arriving at the limiter. The values obtained in low density PLT discharges indicate that sputtering by ions at the limiter and by charge exchange neutrals produce comparable impurity flux rates. Assuming poloidal symmetry, the power loss to the radial scan accessible to the probe was -11-28% of the ohmic power.

*This work was supported by the U.S. Department of Energy Contracts No. EY-76-C-02-3073 and AT(29-1) 789.

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Fig. 1. Schematic of probe: (a) in the plasma boundary, plan view and (b) details of probe.

Fig. 2. Incident deuteron flux to the probe calculated from the trapped ion distribution (a) and ionizing distribution (b) normally incident flux.

Fig. 3. Mean energy, $\bar{E}$, of incident deuterium obtained from saturation behavior (a, O) and from depth profiles (b) for a Maxwellian distribution $n_e = 3 \times 10^{21} \text{ m}^{-3}$.

Fig. 4. Power flux to probe due to deuterium bombardment, calculated from the smoothed curves in Figs. 2 and 3. Correction has been made for the angle of probe with respect to B_z .