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Deposition Probe Measurements of Impurity and Plasma Fluxes Near the Wall in ISX-B

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Deposition probe techniques have been used previously to study the fluxes of impurities and plasma particles incident upon limiter-like probes in the scrapeoff layer of the ISX-B tokamak.[1] In the present work, surface probes are used to measure impurity and plasma fluxes perpendicular to the toroidal field, both at and beyond the radius of the vacuum vessel wall. A comparison of material collected on these wall position samples with the earlier measurements of fluxes parallel to the toroidal field shows that the wall fluxes are far lower for both impurities and plasma particles. In addition, the wall, at a location away from the limiters, is shown to be a source, rather than a sink, of metallic impurities.

High purity amorphous and single crystal silicon substrates were used for the collection of deuterium and impurities respectively. Exposures were made perpendicular to a major radius of the tokamak approximately 120° in the ion drift direction from the limiter. The probe consisted of a disk that could be rotated electrically behind an exposure window so that samples could be changed from outside the tokamak enclosure. The samples were recessed ~2 mm radially behind the edges of an aluminum exposure window that acted as the local "wall". Exposures were made with the probe at the radius of the outer wall of the vacuum vessed ("at wall") and 7 cm outside this radius ("behind wall"). After exposure the samples were removed and analyzed for deuterium content using nuclear reaction analysis ($D(^3He,p)^4He$), and for heavy impurity content using Rutherford ion backscattering (2.0 MeV $^4He^+$). The details of these analysis techniques have been described previously.[1,2]

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The ISX-B vacuum vessel is constructed of type 304 stainless steel and was not gettered for these experiments Operating conditions for the wall position exposures were B_T = 1.3 T, I_p = 170 kA, and $\bar{n}_e = 5 \times 10^{13}/cm^3$, while for the limiter-like measurements they were B_T = 1.5 T, I_p = 120 kA, and $\bar{n}_e = 2 \times 10^{13}/cm^3$. An outer mushroom limiter of TiC coated graphite and an inner stainless steel bar limiter were in use during all the exposures reported.

The fluxes of impurities and deuterium detected on wall-like samples are far lower than those found on limiter-like probes. A comparison of iron and deuterium deposition for at wall, behind wall and limiter-like exposures to typical ohmic discharges in ISX-B is given in Table I. Retained deuterium levels at the wall are an order of magnitude lower, while the iron is 3000x lower. The neutral metallic impurity flux at the wall is clearly much smaller than the ionized metallic flux circulating along magnetic field lines in the plasma edge. The values given for iron at the wall locations are upper limits taken from the samples with the greatest accumulation. Many of the samples show no detectable iron. This variation in retained iron suggests that most of the iron may be deposited during disruptive behavior and that the steady state flux to the walls is lower than indicated. Time-resolved measurements[3,4] that indicate order of magnitude changes in metallic impurity fluxes during a single discharge for limiter-like probes have not yet been made at the wall position.

The quantity of deuterium retained as a function of exposure for the different probe locations is shown in Fig. 1. The upper curve, which shows the amount of retained deuterium on samples exposed perpendicular

to the toroidal field at a radius 2 cm outside the limiter, has been fitted to trapping vs. fluence curves.[5] If an isotropic Maxwellian energy distribution is assumed, this fit results in estimates of fluence and energy of $2 \times 10^{17}/cm^2$-disch. at 50 eV. If such a technique is applied to the wall position samples, we find that the amounts retained are in a region ($\sim 10^{15}/cm^2$) where retention (for $E \geq 50$ eV) vs. incident fluence is linear and an estimate of energy cannot be made. The shape of the experimental curves (Fig. 1) indicates that the energy distribution of the incident particles is neither monoenergetic nor a simple Maxwellian. The data would be consistent with a bimodal distribution having a low energy component (~30 eV) that saturates at $\sim 5 \times 10^{15}/cm^2$ and a high energy tail that remains unsaturated at 18 discharges. It is clear from charge exchange neutral data[6] that such a high energy tail exists, but there are no other diagnostics that are capable of corroborating the low energy flux. The linear portion of the data can still be used to estimate the incident fluence. Results for the at-wall and behind-wall cases are approximately 1.1×10^{16} and $6 \times 10^{15}/cm^2$-disch. The difference in these two values is explained completely by the change in exposure geometry. Measurements of damage to single crystal silicon samples exposed at the wall position give a surface peak yield of $3 \times 10^{16}/cm^2$ after 8 discharges. Such a yield is consistent with a monoenergetic dose of $\sim 7 \times 10^{15}/cm^2$-disch. at 50 eV[7] and thus confirms the above estimates.

If the primary source of metallic impurities in the plasma is charge exchange neutral sputtering of the wall, as has recently been suggested,[8] then such a model should be consistent with the present data. If we use our estimated D flux to the wall and assume a sputtering coefficient of 1×10^{-3} ($D_\perp$ on Si@ ~60 eV), the iron sputtered from the walls is

1×10^{18}/disch. (This figure would correspond to an erosion rate of 2 mm/year in a tokamak operating at a 10% duty cycle.) The iron deposited on the limiter-like probe 2 cm behind the plasma edge, when integrated over the area where such flux is present, is equivalent to 5×10^{17}/disch. Considering the uncertainties involved in the above estimates, this is in reasonable agreement with the estimated total iron input (x ½). If a substantial fraction of the iron were being redeposited on the wall uniformly around the torus it would have been detected on our wall position probes. (5×10^{12} instead of 3×10^{11}). Thus our data are consistent with a model in which most of the metallic impurities are introduced by charge exchange neutral sputtering of the wall and are removed by impact with primary and secondary limiters. Such a scenario would lead to increased metal fluence to the walls in the vicinity of the limiter and could be checked by measurements of wall impurity flux as a function of toroidal position.

In summary, we have shown that metallic impurity fluxes to the wall are far lower (x 3000) than those to limiter-like probes located 2 cm outside the limiter radius. Deuterium fluxes are also lower (x 10) at the wall position are are in reasonable agreement with single crystal silicon damage data. Finally, both wall and limiter position data are consistent with an impurity introduction model in which charge exchange neutral sputtering of the wall is the dominant introduction mechanism.

Table I

Deposition Rate	At Wall	Behind Wall (7 cm)	Limiter (2 cm)
D (/cm^2-disch)	1.9×10^{15}	9.4×10^{14}	1.6×10^{16}
Fe (/cm^2-disch)	$< 3 \times 10^{11}$	$< 2 \times 10^{11}$	1×10^{15}

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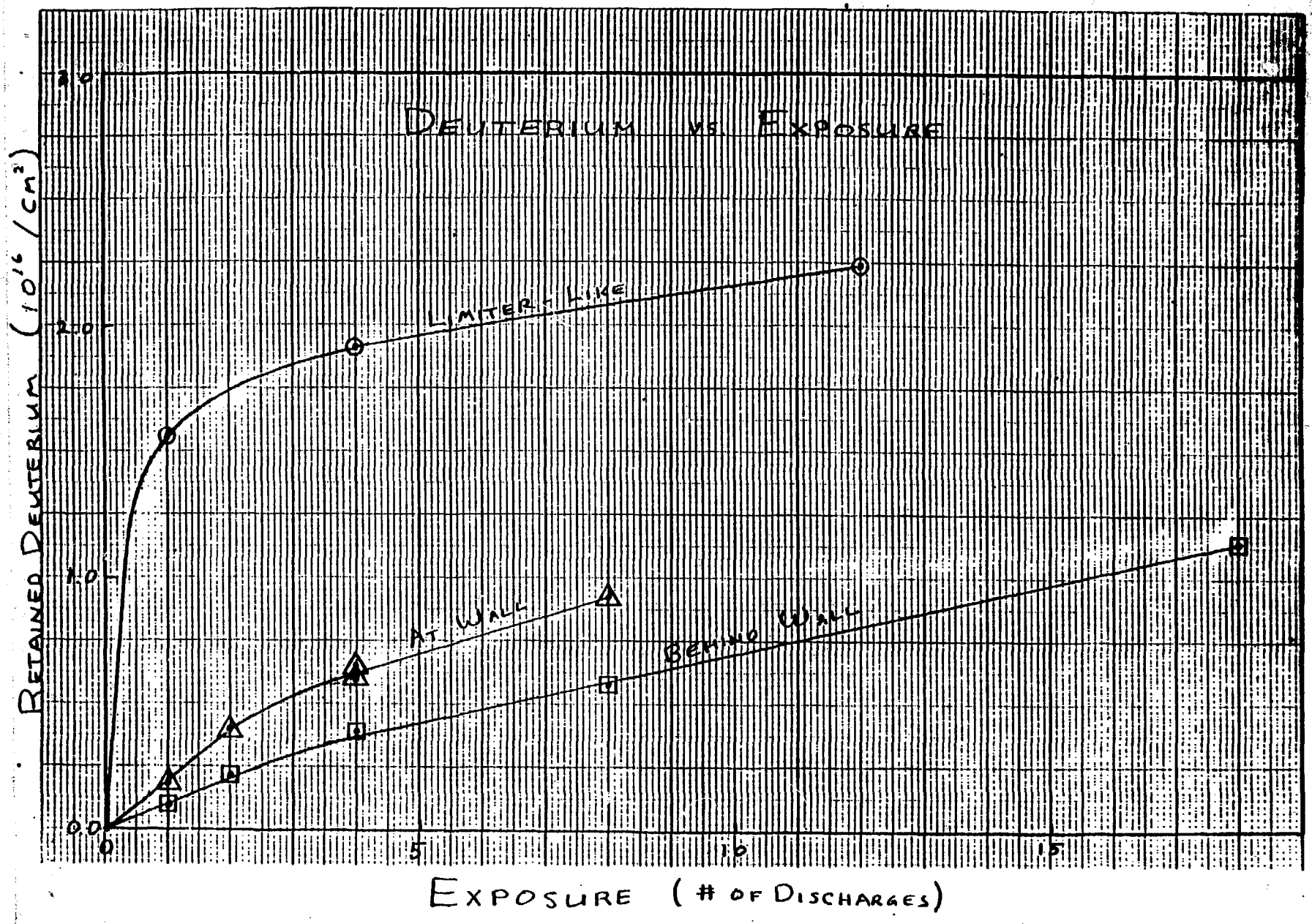
Figure Captions

Figure 1. Deuterium retained in α Si probes vs. exposure for ohmic discharges in ISX-B. ⊙ = Limiter-like, 2 cm outside limiter radius; ▲ = At wall; ⊡ = 7 cm behind wall.

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