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Particle flux and surface interaction in EXTRAP T2R

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Introduction Interaction of the plasma with surfaces in fusion experiments, although occurring at the edges, can lead to the introduction of impurities into the plasma and can affect the conditions in the core. Plasma parameters such as local temperatures and densities and the composition of the plasma facing vessel surfaces are pertinent factors in determining the interactions and resultant impurity releases or recycling [1].

A series of discharges was carried out on the EXTRAP T2R device in order to investigate the surface interaction of the plasma with the stainless steel walls and the molybdenum limiters.

Experimental details and analysis EXTRAP T2R is a medium sized reversed field pinch device - major and minor radii of 1.24m and 0.183m, respectively - with stainless steel walls and molybdenum mushroom limiters covering about 8% of the surface area. An active feedback stabilization system is exists that, through applied control of resistive wall modes, results in reduced plasma wall interaction and a prolongation of the plasma discharge [2].

Spectroscopic measurements of the neutral metallic impurity ions were made using an absolutely calibrated monochromator (focal length 25cm) with photo-multiplier tube (PMT) detector. Narrow wavelength bands (3.1nm) of interest were examined where the light emitted by the plasma was collected along a poloidal line-of-sight through the core.

The good time resolution enabled changes in the emitted intensity could be monitored as the discharge progressed. To simplify comparison with collector probe measurements the measured signal intensities were also integrated from 2ms into the discharge to the end of the discharge and normalised to the length of the integration interval to give the average photon flux. The first 2ms were excluded as these constituted the start-up phase where the plasma current was still rising and for some spectral lines signal saturation was observed. Assuming an electron temperature (T_e) of 5eV and density of $1*10^{12}cm^{-3}$ in the region of primary emission (based on previous EXTRAP T2R measurements) ionisation per photon (S/XB)

factors were obtained [3] and, extrapolating to multiplets if appropriate, the corresponding particle fluxes were calculated.

Collector probe measurements were made (simultaneously to the spectroscopic measurements) using graphite probes at the wall position or inserted into the plasma edge region up to the limiter radius during a number of successive discharges. Following exposure, the probe surfaces were analysed with Rutherford Backscattering Spectrometry using 3.5 MeV $^4He^+$. Compositions were derived by linear fit using the natural isotope ratios and neglecting the background.

Results and discussion A feature of the typical discharge with no active feedback control is the rise of the neutral molybdenum intensity (and that of other neutrals) at the end of a discharge [2]. When active feedback control is applied, this increase is reduced or is absent see Fig. 1. Consequently, there is a difference in the measured particle fluxes of the molybdenum (Mo) and chromium (Cr) between the two cases. This is illustrated in Fig. 2 which shows the calculated average Mo and Cr particle fluxes for a series of discharges with and without the use of feedback control in both H_2 and D_2 plasmas. The average Mo particle flux is seen to reduce by 40% with feedback control in H_2 discharges and by 55% in D_2. Similarly, the average Cr particle flux decreases in discharges using feedback control with a greater reduction in D_2 discharges. The flux of Cr is larger than of Mo by a factor of approximately 1.7 in H_2 (2.1 in D_2) during feedback controlled discharges whilst without feedback control this factor is 1.2 in H_2 (and 1.4 in D_2). This indicates that the effect on the particle flux of applying feedback control is more significant for the Mo than the Cr.

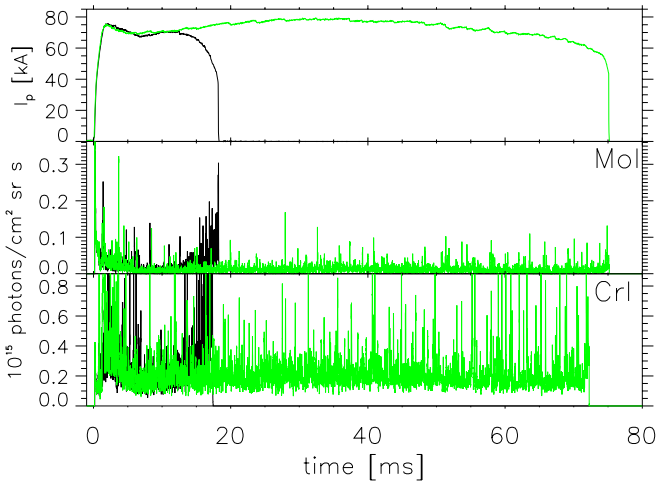

Fig. 1: Typical time traces of the plasma current I_p, MoI and CrI during H_2 discharges with feedback control (green) and without (black).

The spectroscopic results are very dependent on the assumed T_e through the S/XB. For example, a T_e of 2eV or 10eV instead of 5eV would result in 30% or 130% of the Cr (359nm triplet) particle flux, respectively. Mo spectral lines at both 380nm and 319nm have been used and have slightly different dependencies, giving 25% or 160% of the flux for the 380nm line and 34% or 150% for 319nm at the other T_e. Additional uncertainties arise from

the quartz windows on the vessel which are not included in the absolute calibration. Deposits build up on the plasma side over long term operation and any absorption that may occur will lead to an underestimation of the particle flux from the detected light.

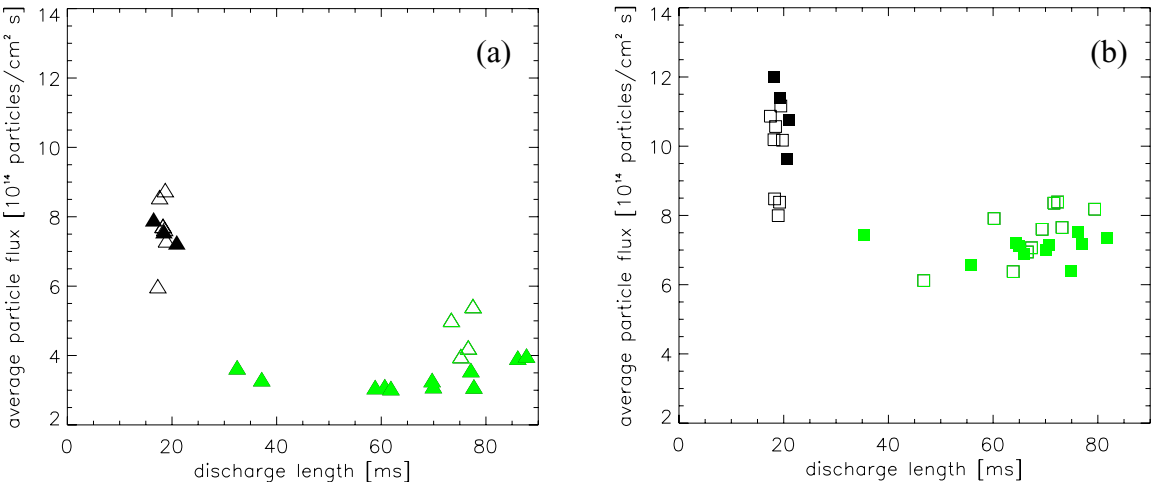

Fig. 2: Average particle fluxes for (a) molybdenum (Δ) and (b) chromium (□) in H_2 (open symbols) and D_2 (filled). Discharges longer than 30ms (green) have active feedback control.

The 3.5 MeV RBS spectrum from the analysis of the collector probe X exposed to H_2 discharges with feedback is shown in Fig. 3 with a linear fit of the expected yields from Cr, Fe, Ni and Mo, using constant energy resolution of 9keV (standard deviation).

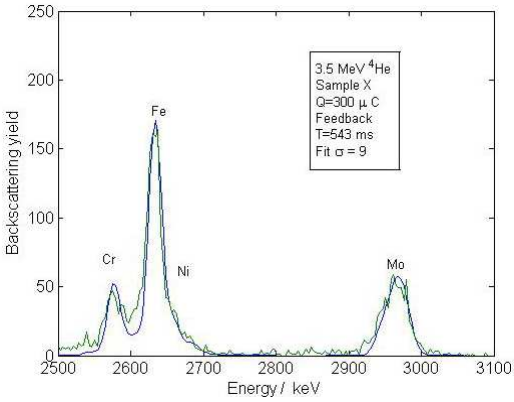

Fig. 3: RBS spectrum from probe X exposed in 8 H_2 feedback discharges.

The absolute areal density of Mo can be determined quite accurately, whereas the amounts of Cr, Fe and Ni are more uncertain due to the low concentrations of Cr and Ni. The average deposition rates of the metal components on the probes are shown in Table 1.

We can see that, the average deposition rates of Fe and Mo were 40-50% higher without active feedback than with feedback applied. The Fe and Mo rates are also observed to be 60% higher in D_2 than in H_2 plasmas. In the case of without feedback D_2 plasmas the average Mo deposition rate was more than 100% higher than the other Mo cases.

The metals sources are the Mo limiters and the SS316L wall. The composition of SS316L is specified as: Fe, <0.03% C, 16-18.5% Cr, 10-14% Ni, 2-3% Mo, <2% Mn, <1% Si, <0.045% P, <0.03% S, or as far as our relevant metals are concerned, the composition of Cr:Fe:Ni is roughly 0.25:1:0.18.

probe	Cr 10^{15} at/cm^2 s	Fe 10^{15} at/cm^2 s	Ni 10^{15} at/cm^2 s	Mo 10^{15} at/cm^2 s	exposure time [ms]	feedback control	ion species
X	1.01	2.61	0.41	0.54	543	on	H
XI	1.36	3.94	0.69	0.77	148	off	H
XVII	2.58	4.13	0.60	0.76	489	on	D
XVIII	4.3	6.4	1.3	1.8	153	off	D
XX	2.3	4.2	0.86	0.88	909	on	D

Table 1: Average deposition fluxes of the collector probes.

Plausible impurity production mechanisms are physical sputtering, thermal evaporation and unipolar arcs. If we consider just sputtering by the majority ions, the sputtering yields may be approximated with Bohdansky's formula for low energy sputtering [4]. The sputtering yield is everywhere at least twice as large for D compared to H and for the lower energies, approaching threshold, the difference is larger. The probe results show a larger metal flux in both feedback and non feedback cases in the D_2 plasma than in H_2 which could support sputtering as a cause, although the increase is less than a factor of 2 and the difference in the spectroscopy results is smaller still.

The evaporation rate at surfaces which are exposed to excessive heat load can be roughly estimated by the Knudsen law, using the Clausius-Clapeyron equation for vapour pressure. A very strong surface temperature dependence is seen with the characteristic temperature for Mo lies at least 1000 K above that of Cr, Fe and Ni. The vapour pressure, and evaporation rate of Cr lies nearly a factor two above that of Fe, which in turn lies a factor 2 above that of Ni, so if melting occurs at the wall, one would expect the resulting evaporation flux of Cr to be enhanced and the flux of Ni to be suppressed, with respect to the surface composition. Indeed, relative to the stainless steel proportions, the probe results show an enhanced Cr flux. The Ni flux is not suppressed but is the most uncertain.

Conclusions Quantitatively, there is good agreement between the average particle fluxes calculated from the spectroscopy and the probes, in particular, all cases of the H_2 results. There is more of a difference in the D_2 Cr results. Both measurement techniques show an decrease in the metal impurity flux when feedback control is used. The probe results clearly show increased fluxes in D_2 compared to H_2.

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[4] J Bohdansky, in Data Compendium for Plasma-Surface Interactions, Nuclear Fusion Special Issue (1984) 61-71