EFFECT OF grad(B)-INDUCED DRIFT ON THE ABLATION HISTORY OF PELLETS: RESULTS OF SCENARIO CALCULATIONS

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As is known, high-density clouds of ablated particles evolve around hydrogen fuel pellet injected into hot plasmas. Apart the direct deposition of the ablated pellet particles and their diffusion to adjacent domains, grad(**B**)-caused drift can transport pellet particles to regions not directly accessed by the pellet. The deposition profile of the pellet particles may notably be altered if particle drift is present.

On the other hand, drift can only influence the ablation characteristics if the plasma state parameters, temperature and density in particular, are modified in the region ahead of a moving pellet. In the case of pellet injection at oblique angles, for example, the particles drift in a purely radial direction whereas the pellet moves towards the plasma centre along its own trajectory. In such a case, it is not obvious whether or not drift will affect the ablation history.

If the plasma state parameters are affected in front of the pellet and thus enhanced shielding is present, the measured penetration depths should notably exceed predicted values corresponding to the absence of drift.

To examine these phenomena, scenario calculations were performed by means of a quasi-three-dimensional pellet code [1] both for LFS and HFS pellet injection scenarios in ASDEX Upgrade (AUG) at different injection angles: 0^0, 108^0, and 135^0 measured in the poloidal plane with respect to the the equatorial plane. In this series of calculations, drift and all its possible effects on the ablation process were intentionally ignored.

In the scenarios corresponding to zero degree injection angle (LFS shots), the pellet is moving inward whereas the drift is directed outward. Hence the region in front of the pellet is not being modified by drift. However, since charged particles are expected to drift away from the flux tube enclosing the pellet both in the case of LFS and HFS shots, the magnitude of local shielding may somewhat be reduced in both cases. Since the pellet is surrounded by a thick cushion of high-density neutrals, and the drag forces acting on the neutral cloud in this region cannot be very high, it is reckoned that this effect is, in a first approximation, negligible. Hence, in the case of LFS shots, if the computational model is accurate enough and this local drift is negligible, the measured and computed penetration depths should not be far from each other.

The global pellet code used in these calculations is described in detail in [1]. It has been previously applied to impurity pellet injection scenarios in ASDEX Upgrade (Ne) and Wendelstein W7-AS (C pellets). Rather good correspondence among the measured and calculated penetration depths was reported [1,2]. The code complex consists of three major modules:

- a $1\frac{1}{2}$D resistive MHD code describing the B-perp motion, ionization, deceleration, and the magnetic confinement to flux tubes of the ablated particles, the local value of the confinement radius in particular;

- a 1D code describing the B-parallel expansion and heating of the ablated and confined (to flux tubes) pellet particles, accounting for shielding effects (collisional and electrostatic), and calculates the resulting local ablation rates;

- a transfer module accounting for the pellet motion across the magnetic flux surfaces and the evolution of the ablation process along the pellet path.

The computations were performed in the following manner. For a set of measured plasma temperature and density profiles recorded for a time instant immediately before pellet injection, the corresponding topology of the magnetic flux surfaces was computed. With the help of this chart, the magnitude of the 'energy reservoirs' between the flux surfaces and the temperature and density distributions along the (oblique) pellet paths were determined. With the set of input data thus prepared, the actual pellet computations were started.
A summary of the results of scenario calculations and their comparison with measured results is shown in Table I.
In analyzing the results, it should be noted that
1.) The size of the pellet entering the plasma could not be measured in the series of experiments considered here. Shot No #14023 was performed with a special diagnostic setup to get profiles just before and after the injection. Hence the pellet particle deposition profile and also the total number of particles refound in the plasma could be determined. This number uniquely defines for this case the initial pellet size and the associated particle losses in the guiding tube. The characteristics of this shot may be used as reference quantities while analyzing the rest of the discharges considered.
In all other cases, the mass losses (initial pellet sizes) represent assumed quantities. Higher mass losses are associated with longer guiding tubes and or higher pellet velocities.
2.) The nominal pellet size, 1.9x1.9x2 mm^3, corresponds to an equivalent pellet radius of 1.24 mm. The effective pellet radii used in the calculations correspond to the following mass losses in the guiding tubes: 1.20 mm - **10**%, 1.023 mm - **44**%; 0.99 mm - **50**%; 0.945 mm - **56**%; 0.915 mm - **60**%.
3.) In some cases, the duration of the diode signal could not be established uniquely (precursor signal possibly due to driver gas puff, etc.). In such cases the min and max values are tabulated. The values of experimental penetration depths, λ_{expr}, were calculated by assuming constant pellet velocities along the designated straight injection path.
4.) In those cases where error bars were provided for the temperature and/or density profile measurements (#14023), or the n_e measurements displayed large scattering and therefore upper and lower bounds were used in the corresponding calculations (#9530), several (alternative) penetration depths were calculated.
The ablation history curves corresponding to the different alternatives deduced from the error bars of the measured values of shot #14023 are given in Figure 1. An essential information gained from this figure: the effect of the error bars of the T_e and n_e measurements on the resulting penetration depth values is ca. 2.0 cm on each side of the penetration depth corresponding to the 'averaged' T_e,n_e curves.
5.) In the case of shot #10636, the pellet was broken and therefore the diode signal could not be interpreted uniquely.
6.) In the case of shot #13999, the pellet size used in the computations was somewhat smaller than in comparable scenarios. Hence the computed and tabulated penetration depths are presumably by 1 to 2 cm shorter than they should be. Furthermore, in the case of this shot the lengths of the diode signals were not in agreement with results stemming

from other optical measurements. Nevertheless, the calculated penetration depth values seem to correspond to the durations of the diode signals monitored. A rather long diode signal with a 'precursor' may be due to a puff of the driver gas.

Conclusions

As can be seen from Table I, for the pellet injection angles considered and within the limits of accuracy of the measured data used as input parameters for the calculations, there is no notable effect of the -grad(**B**)-induced drift on the ablation history. Also the HFS injection cases considered could be modelled, with acceptable accuracy, by a pellet code in which straight pellet trajectory is assumed and drift is intentionally ignored.
Apparently, only if the pellet path is aligned, at least temporarily, with the drift motion, and the drifting particles are deposited still within the pellet penetration depth, (and do not have sufficient time for escaping along the field lines), can one expect notable effect on the ablation history.
The reduction of local shielding due to drift, that should affect both LFH and HFS pellet injection scenarios, seem to be negligible.
The particle penetration depth calculations performed (standard stopping length calculations, see [1]) indicate that the drifting ions do not reach the pellet surface at any time because of the low range of particle energies involved (see Figure 2). Hence direct momentum transfer from the drifting ions to the ablating pellet and the associated pellet path deflection do not seem to be probable. The pellet seems to traverse the plasma, at least in the cases analyzed, unaffected by the drift of the ablated particles. To clarify the details of this phenomenon, further experiments seem to be necessary.

References

[1] L.L. Lengyel, et al., Nucl. Fusion **39** (1999), 791;
[2] A.A. Ushakov, et al., Proc. EPS 1999, P4.030.

TABLE I: Comparison of Measured and Calculated Results

ShotNo	time (s)	Angle (degr)	v_p (m/s)	r_p (mm)	Diode (μs)	λ_{expr} (cm)	λ_{calc} (cm)
# 9530	3.05482	0	560	1.20	340/390	19.0/21.8	**17.5-24.5**
# 9684	3.18428	0	560	1.20	300	16.0	**17.0**
# 9698	3.58508	0	560	1.20	220/360	12.3/20.	**15.5**
#12139	5.58551	0	240	1.20	980	23.5	**23.0**
#13999	4.47246	108(72)	560	0.915	350/600	19.6/33.6	**21.2**
#13999	4.50995	108(72)	560	0.915	340/440	19.4/24.6	**22.2**
#13999	4.55997	108(72)	560	0.915	400/900	22.4/50.4	**21.5**
#13999	4.60770	108(72)	560	0.915	400/500	22.4/28.0	**25.5**
#14023	2.3910	108(72)	240	1.023	730/770	17.5/18.5	**17.2-21.6**
#14024	2.36202	108(72)	560	0.945	420	23.5	**20.0**
# 9859	2.30511	135(45)	240	0.99	1090	26.2	**20.0**
#10479	2.56068	135(45)	240	0.99	1000	24.0	**18.0**
#10533	2.20821	135(45)	240	0.99	800	19.2	**19.0**
#10537	2.55518	135(45)	240	0.99	900	21.6	**21.0**
#10636	2.73982	135(45)	240	0.99	820/1200	19.7/29.0	**19.0**
#10778	1.66522	135(45)	240	0.99	970	23.3	**24.5**
#10778	2.65900	135(45)	240	0.99	900	21.6	**21.0**

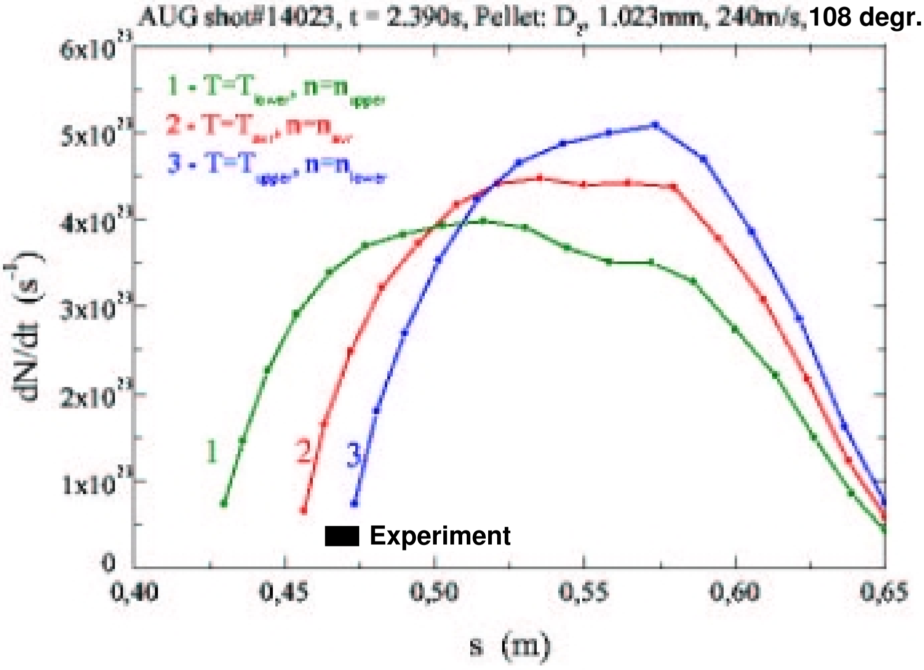

Figure 1: *ASDEX Upgrade shot #14023, t = 2.390 s: Calculated ablation rates and penetration depths for various combinations of the measured undisturbed T_e and n_e distributions. Index 'upper' - upper bound, 'lower' - lower bound.*

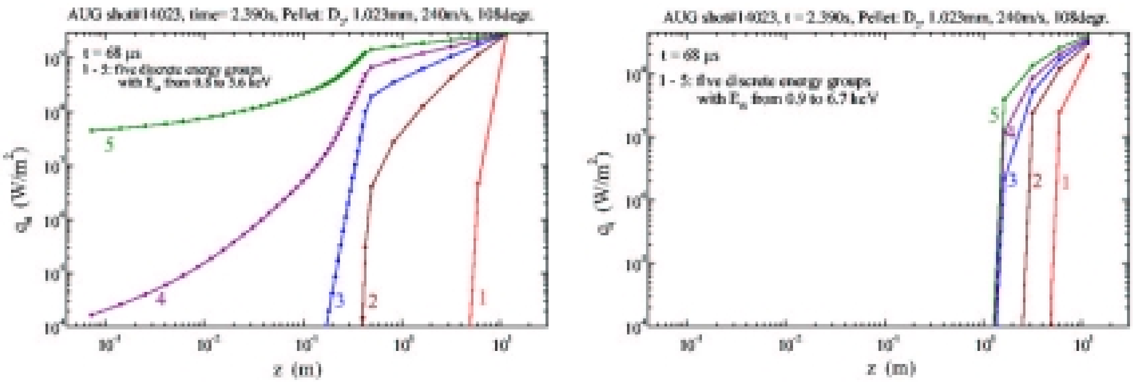

Figure 2: *Energy flux depletion of energetic plasma electrons (left) and ions (right) in the ablatant cloud along the magnetic field lines. The flux depletion is a measure of the particle penetration depth. Note the low penetration depths of ions. For comparison: an ion drifting across the magnetic field with a velocity of $10^4 m/s$ has a kinetic energy of about 1 eV.*