PELLET PENETRATION IN ASDEX: A COMPARISON OF RESULTS COMPUTED BY MEANS OF THE ORNL ABLATION MODEL WITH MEASURED DATA

L.L. Lengyel, K. Büchl, and W. Sandmann

Max-Planck-Institut für Plasmaphysik, EURATOM Association,
D-8046 Garching, Fed. Rep. of Germany.

The neutral gas plasma shielding (NGPS) ablation model recently proposed by Houlberg et al. /1/ has been extensively tested on pellet penetration depths measured in JET /2/. The best fit among calculated and measured penetration depths was obtained by assuming a shielding cloud radius 1 mm larger than the local pellet radius: $R_{cl} = r_p + 1mm$, yielding maximum shielding at the end of the pellet lifetime ($r_p = 0$).

Recently, a model was developed that describes the time evolution of particle clouds in plasmas /3/. With the help of this model, the ionization radius, i.e. the radius of the shielding cloud, can be calculated as a function of the local ablation rate. The results of these calculations show that the shielding cloud radius is proportional to the number of particles locally deposited. The cloud expansion code can be combined with the ORNL ablation model with an R_{cl} feedback option between the two models.

Calculations are performed here for a number of randomly selected pellet-fuelled ASDEX shots. The pellet penetration is calculated for the measured $T_e(r)$ and $n_e(r)$ profiles by means of the ORNL ablation code with and without R_{cl} feedback active.

Eight ASDEX shots were selected for which the temperature and density data sets are complete (the radial distributions of T_e and n_e were reconstructed by fitting the data measured at 16 points and stored in the ASDEX data bank 'DABA' by means of spline functions). The central T_e and n_e values ranged in these shots from 0.5 to 0.75 keV and from 0.5 *to* 1.7 ($\times 10^{20}$) m^{-3}, respectively ($a = 0.4\ m$). The pellet penetration depths were measured by two different means: H_α radiation emission (constant pellet velocity assumption) measurements and direct photography in the visible light range. The pellet injection velocity was 650 m/s in all eight cases (centrifuge was used as pellet injector). The pellet sizes and the equivalent (spherical) pellet radii used in the calculations are displayed in Table 1. The plasma data were recorded during pellet injection (a string of approximately 20 pellets injected) typically at every 17 ms. The quantity Δt_{pre} represents the time delay between pellet injection and the nearest previous recording time. The quantity Δt_{post} is the time delay between the nearest recording time following pellet injection and the injection time. The particle content of the discharge is computed at every recording time by volume-integrating the measured density distribution (data evaluation program still under development). The ratio $\Delta N_{pla}/N_{pel}$ is supposed to show the fraction of pellet particles actually recovered in the plasma. This quantity, also displayed in Table 1, shows unusually large scattering, unrelated to Δt_{post}, which makes the value of the effective pellet mass estimated on the basis of this ratio rather uncertain. (For example, the value given for shot #18711/#12 is in clear disagreement with the results of some auxiliary diagnostic checks.) Further quantities displayed in Table 1 are the experimental penetration depths determined by two different means and the one calculated on the basis of the ORNL ablation model with Rcl feedback active, and the calculated value of the shielding radius R_{cl} at the location of the maximum ablation rate. Finally, the central electron temperature and the maximum temperature 'seen' by the pellet at the end of its lifetime are also displayed. Because of the large scattering in the mass fraction values specified and the associated effective pellet radii, the calculations were repeated with an ad hoc constant mass fraction (=0.75). The resulting data are displayed in Table 2. In the same table, the pellet penetration depths calculated with the ad hoc assumption $R_{cl} = r_p + 1\ mm$ are also displayed (the values in parentheses). In spite of the substantial uncertainties regarding the actual pellet masses affecting the plasma, the following conclusions can be made:

(1) The penetration depths calculated by means of the NGPS ablation model with the R_{cl} feedback active lay within the range of the measured values.

(2) The duration of the H_α trace (in combination with the assumption of constant pellet velocity) does not always suffice for reliable determination of the pellet penetration depth.

(3) The effective shielding cloud radius at the location of the maximum ablation rate (i.e. close to the end of the pellet lifetime) is between 2.5 to 3.5 mm for the ASDEX plasma parameter ranges tested.

(4) The magnitude of the shielding cloud radius significantly affects the ablation rate and thus the penetration depth. The empirical or effective shielding cloud radii do not seem to be transferable from machine to machine (or from parameter set to parameter set). The replacement of the shielding radii calculated here with those stemming from the (JET) assumption $R_{cl} = r_{pel} + 1\ mm$ yields, under the ASDEX conditions tested and with the uncertainities described, penetration depths substantially different from the measured ones.

(5) Reliable validation calculations require at least a few shots with the following sets of experimental data:

5.1 Electron temperature and density distribution recordings immediately (i.e. with the minimum possible time delay) before and after the moment of pellet injection.

5.2 Reliable particle balances at the same time instants.

5.3 Measurement of the mass and velocity of the pellet just before its entry into the plasma and control of the pellet velocity during the flight time (checking its constancy), particularly at the time of maximum ablation rate.

5.4 Accurate determination of the pellet lifetime and of the associated penetration depth, if possible, by two independent means.

One will note that the sets of experimental data analyzed here did not in all cases simultaneously satisfy all the conditions (5.1 to 5.4) specified .

Shot No.	N_{pel}	r_{pel}	$\frac{\Delta N_{pla}}{N_{pel}}$	r_{peff}	Δt_{pre}	Δt_{post}	Penetration depth (cm)			R_{cld}	$T_e(0)$	T_{abl}
Pellet No.	(10^{19})	(mm)		(mm)	(ms)	(ms)	H_α	Photo	Calc.	(mm)	(keV)	(keV)
18710												
#1	2.9	.484	.46	.373	6.4	11.	17	25	18.5	3.4	.740	.528
#11	2.8	.479	.15	.254	10.8	7.0	19	26	16.1	2.5	.646	.396
#12	4.8	.573	.77	.524	7.7	9.0	24	27	32.1	3.0	.706	.649
18711												
#1	3.5	.516	1.0	.516	8.8	9.0	19	27	25.7	3.6	.746	.649
#11	4.4	.556	.60	.469	12.9	5.0	29	28	32.1	2.6	.553	.533
#12	4.2	.548	.10	.254	8.5	10.	25	26	17.7	2.2	.541	.346
18717												
#1	4.2	.548	1.0	.548	1.3	16.	18	27	28.9	3.6	.756	.676
#11	4.3	.552	.13	.282	7.8	9.0	25	29	18.5	2.5	.543	.404

Table 1

The ASDEX shots with pellet injection analyzed. The mass loss fraction computed by the ASDEX data analysis program was used to estimate $(r_p)_{eff}$.
Notation: N_{pel} - number of D atoms in the pellet, ΔN_{pla} - particle (electron) increment detected in the plasma following pellet injection, $(r_p)_{eff}$ - effective spherical pellet radius used in the ablation calculations; $\Delta t_{pre}, \Delta t_{post}$ - time delays before last data recording prior to and first data recording after pellet injection in relation to the pellet injection time, R_{cl} - calculated shielding cloud radius. $T_e(0)$ - central electron temperature, T_{abl} - electron temperature "seen" by the pellet at the end of its lifetime.

Shot No. Pellet No.	N_{pel} (10^{19})	r_{pel} (mm)	$\frac{\Delta N_{pla}}{N_{pel}}$	r_{peff} (mm)	Δt_{pre} (ms)	Δt_{post} (ms)	Penetration depth (cm) H_α	Photo	Calc.	R_{cld} (mm)	T_{abl} (keV)
18710											
#1	2.9	.484	.75	.440	6.4	11.	17	25	21.7 (29.7)	3.6	.583
#11	2.8	.479	.75	.435	10.8	7.0	19	26	26.5 (34.5)	2.8	.549
#12	4.8	.573	.75	.520	7.7	9.0	24	27	31.3 (40.9)	3.0	.638
18711											
#1	3.5	.516	.75	.468	8.8	9.0	19	27	23.3 (32.1)	3.5	.614
#11	4.4	.556	.75	.506	12.9	5.0	29	28	35.3 (51.3)	2.6	.545
#12	4.2	.548	.75	.498	8.5	10.	25	26	36.9 (52.1)	2.5	.535
18717											
#1	4.2	.548	.75	.498	1.3	16.	18	27	25.7 (35.3)	3.5	.631
#11	4.3	.552	.75	.502	7.8	9.0	25	29	34.5 (50.5)	2.6	.543

Table 2:
The same shots as those displayed in Table 1, but with constant ad hoc mass fraction (=0.75) assumed. Numbers in parentheses represent penetration depths based on the $R_{cl} = r_p + 1mm$ assumption in the ablation rate calculations.

/1/ W.A. Houlberg et al., Nucl. Fusion **28** (1988), 595.
/2/ M.L. Watkins et al., Proc. 14th Eur. EPS Conf., Madrid, **11D**, (1987) 201.
/3/ L.L. Lengyel, Phys. Fluids **31** (1988), 1577.