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Modeling of cryogenic hydrogen isotope pellet ablation and cloud expansion

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For a better understanding of the pellet ablation, cloud expansion and radiation of the pellet cloud the hydrodynamical code developed at IPP Garching [1] has been modified and new physics has been added. According to the experimental observation the cloud which is formed around a pellet interacting with the hot plasma is composed of two regions. Around the pellet a neutral cloud is formed. Further away from the pellet this cloud gets ionized and undergoes a channel flow along the magnetic field lines. According to this observation we simulated the phenomena by taking into account the simultaneous presence of different cloud parts.

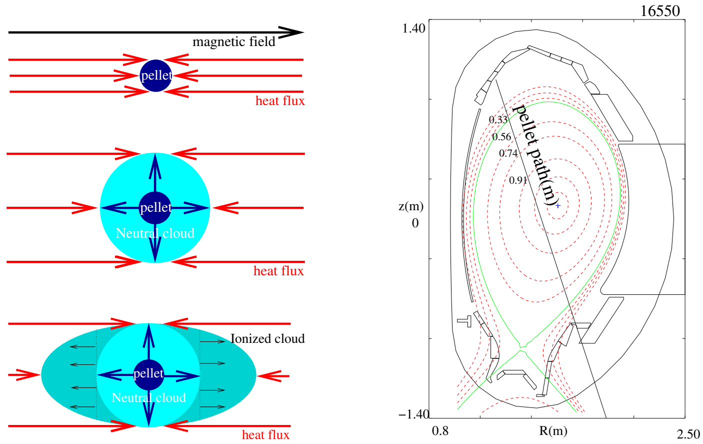
The possibility of combining the physics of neutral cloud formation and ionized cloud evolution has been checked. A new module which describes the neutral cloud has been introduced. In the enhanced hybrid model the neutral cloud is described by the neutral gas shielding (NGS) ablation model and the dynamics of the ionized cloud part is treated by an one-dimensional Lagrangian cell code.

According to this physical picture the energy flux carried by the hot background plasma ablates the pellet. As a result of the ablation a quasi steady state neutral cloud is formed around the pellet. The spherical expansion of this cloud is stopped by the magnetic field as the cloud gets ionized. This procedure is described in the code by a routine which calculates the radius of the flux tube where the ablated material is deposited.

Far away from the pellet the cloud undergoes a chanel flow, as can be seen in fig. 1. The formation and the dynamics of the ionized cloud is described by the 1D Lagrangian code. This part of the code also calculates the shielding of the cloud. This way the reduced energy flux of the background plasma which reaches the neutral cloud is determined by this routine also. The ablation of the pellet is due to this reduced heat flux and the ablation rate is calculated according to the NGS formula [3].

The NGS and 1D Lagrangian model can be combined, because the size of the neutral cloud [2] is smaller than the radius of the ionized cloud. As the pellet penetrates deeper and deeper into the plasma the neutral cloud travels with it, but the ionized cloud is left behind. The trajectory of the pellet can be seen on fig.1b.

The penetration depth is known from the experimental observation. We calculated the ablation rate and the penetration depth of the pellet to compare the results obtained by the code with the experimental one. The size of the radiating cloud along the



(a) (b)

Figure 1: *a) The scheme of pellet ablation. b) ASDEX Upgrade cross section and injection geometry*

magnetic field lines is measured by imaging the light emitted by the pellet cloud in the visible range. The code also gives the distribution of the radiation. The obtained size has been compared with the experimental results.

To obtain the density and temperature profiles along the pellet path for ASDEX Upgrade shots an interface has been developed to the shot file system. As a first approximation it has been supposed that the pellet trajectory is a straight line and the pellet velocity is constant. According to the actual position of the pellet injection the pellet enters the torus at R=1.250m (major radius), z=1.0m (elevation) under an angle of 72° relative to the horizontal axis (high field side injection).

The results obtained by the code for shot #16550 are shown in fig.2. In this case the pellet has been injected from high field side (HFS), having equivalent radius of 0.7 mm and velocity 1000m/s. The ablation rate and the pellet radius reduction along the pellet path can be seen. The density and temperature of the background plasma are also shown. The toroidal distribution of the pellet cloud has also been compared with the experimental data, as it can be seen in fig. 3a and 3b. Both experimentally and theoretically has been obtained that the cloud length is in the range of 2-10 cm. The correspondence between the experiments and simulations is quite good, in spite of the fact that the drift effects (which are important for HFS injection) are neglected in the code.

In a first application, this tool was applied to determine the pellet position, when edge localized modes (ELM) get triggered by the pellet introduced perturbation. For this purpose shot #17455 has been investigated [4]. The pellet size was 0.4 mm ($3.45 \cdot 10^{19}$ particles) and it has been injected with 1000m/s velocity.

To understand how a pellet can trigger an ELM we should know the perturbation which is induced in the plasma. For this purpose we calculated the instantaneous

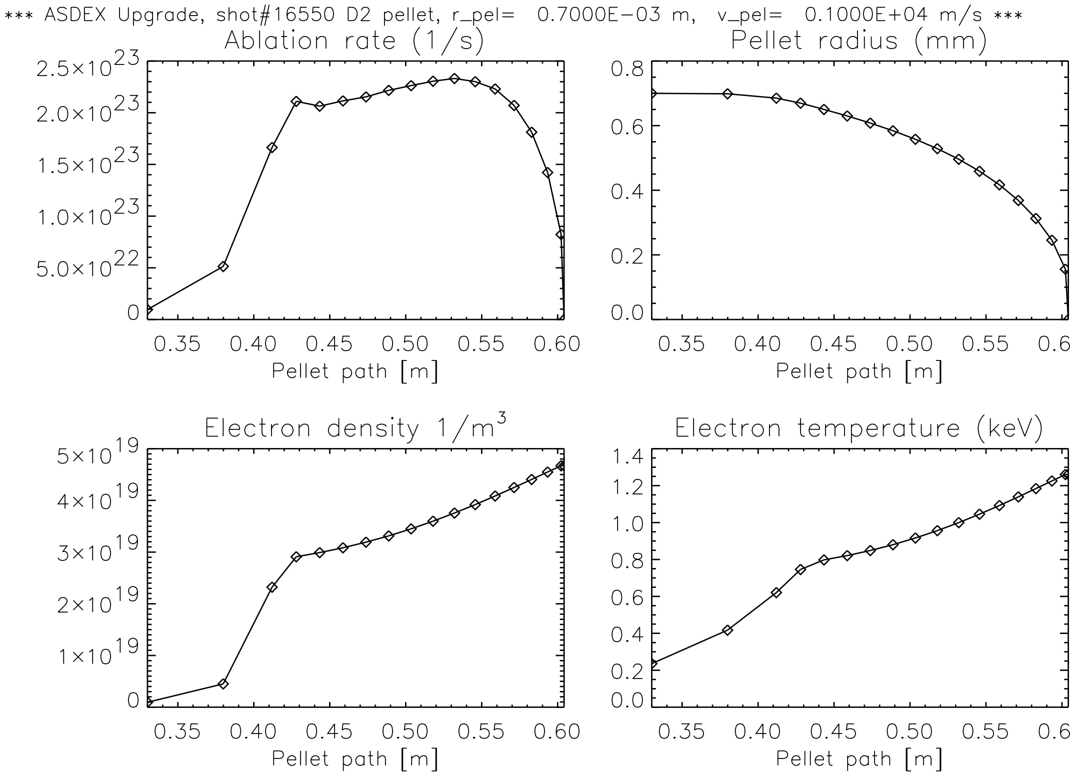
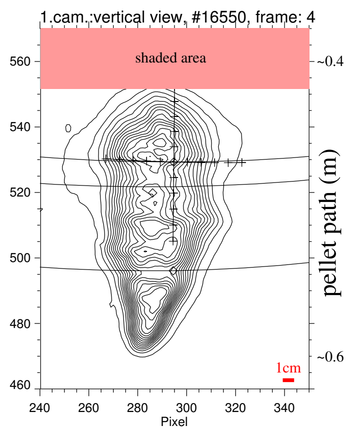
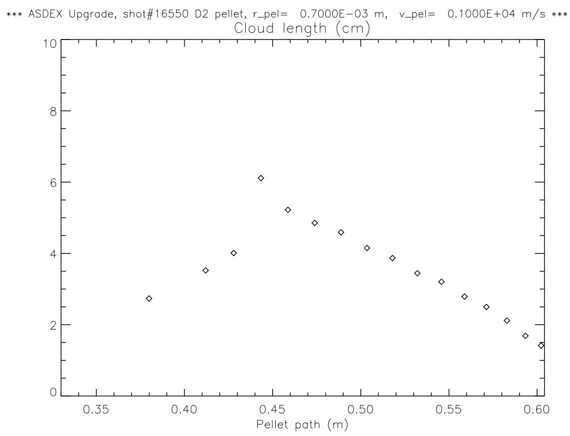


Figure 2: *The ablation rate (top, left), the pellet radius (top, right) and the parameters of the background plasma for shot #16550 (ASDEX Upgrade) are shown. (The experimentally obtained penetration depth is 22cm.)*



(a)



(b)

Figure 3: *The experimental (a) and simulated (b) cloud sizes determined from the distribution of the cloud radiation for shot #16550.*

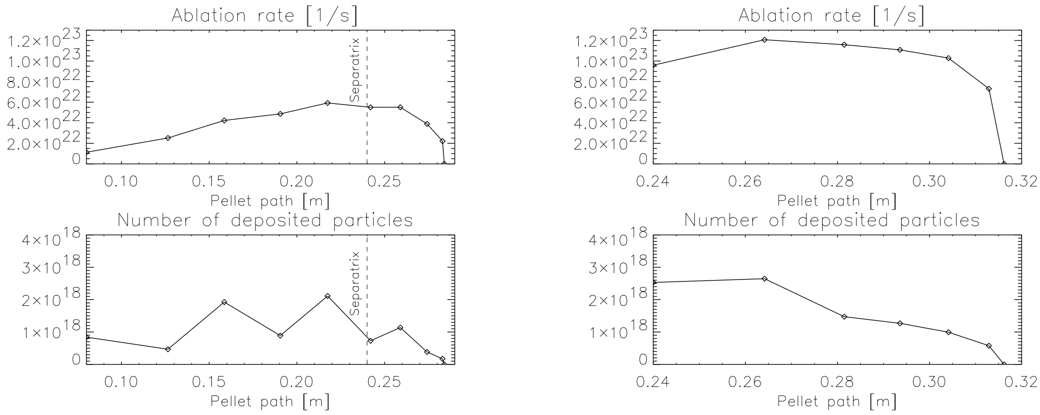


Figure 4: Pellet ablation rate and number of deposited particles are shown for shot #17455. The figures on the right hand side show the results when the calculations of pellet ablation started already in the SOL. On the left hand side are shown the results when the ablation it is supposed to start just in the core plasma, ignoring the SOL.

number of the deposited particles and compared with the number of the particles of the background plasma [4]. The ablation rate for shot #17455 and the number of deposited particles are shown in fig.4. First we supposed that the pellet starts to ablate as it reaches the plasma. It can be seen that already in the scrape-off-layer (SOL) the number of the deposited particles is 10^{19}, which is comparable to the total number of particles in the SOL (10^{19}) . This amount of particles can cause considerable plasma cooling. This way the ablation rate in SOL should be smaller than the calculated one, but anyhow there is a considerable material deposition. To determine exactly the perturbation induced by the deposited material we should know the volume of flux tubes and the exact magnetic structure along the pellet path, which is a subject for future work. We also calculated the ablation rate and the number of deposited particles when the calculations starts at the separatrix. It can be seen, that at the separatrix the ablation rate is in the order of $10^{23}s^{-1}$, which means that in the SOL, around the separatrix, the ablation rate should be high and the material deposition cannot be neglected.

The calculation of the pellet ablation and cloud expansion on a pellet path given by the experimental observations has been calculated with the hybrid code. The cloud size determined with this new method gives results which are in good agreement with the experimental observations. We also determined the perturbation caused by small pellets which are quite interesting to understand the ELM triggering mechanism induced by pellets. If the temperature and density of the background plasma are high enough the pellet deposits a huge amount of material already in the SOL, which can cause considerable hydrodynamic perturbations, this way the ELM will be triggered before the pellet reaches the pedestal top.

References

[1] L.L Lengyel et al., Nucl. Fusion, Vol 39, No. 6, p 791, 1999.

[2] B. Pégourié et al., Nucl. Fusion, Vol 33, No. 4, p 591, 1993.

[3] S. Kálvin et al., Europhys Conference Abstracts Vol. 27A, P-3.154.

[4] P.T. Lang al., Nucl. Fusion, Vol 44, No. 5, p 665, 2004.