Study on dynamics of ablation plumes produced by fusion products in laser fusion liquid wall chamber

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Abstract. An integrated ablation simulation code DECORE (DEsign COde for REactor) has been developed to analyze characteristics of plumes produced by ablation, and also an integrated code for condensation of a plume DECORE-condensation has been developed to clarify the ability of the chamber clearance. Characteristics of a plume produced by ablation in liquid wall chamber of KOYO-fast have been analyzed. A plume produced by ablation moves with velocities of a few km/s. Formation of clusters in a plume with hydrodynamic motion is carried out. Radius of clusters in a plume in liquid wall chamber of KOYO-fast is mainly from 25 nm to 35 nm.

1. Introduction

One of the critical issue of a laser fusion reactor with a liquid wall is the chamber clearance. After micro explosion with 200 MJ nuclear yield, roughly 10 kg of liquid metal ablates from the surface due to heating by X-rays, \( \alpha \) particles, and debris ions from the target. The plume produced by ablation makes mist and clusters after expansion cooling. Such clusters would attach on the injected target surface and degrade the target performance and preheat of the fuel.

In this study, an integrated ablation simulation code DECORE (DEsign COde for REactor) has been developed\cite{1} to analyze characteristics of plumes produced by ablation.

A new model on stopping power in high Z and low temperature plasmas has been developed in this study. Temperatures, densities, and velocities of ablated lead are obtained using DECORE \cite{1} for the case of first ignition with 200 MJ power output KOYO-fast\cite{2}. In DECORE, phase transition (from liquid to gas (plasma)), hydrodynamic motion of gas (plasma), and radiation transport are considered. Ablated plume moves with velocities of a few km/s.

An integrated simulation code for condensation of a plume DECORE-condensation has been developed to clarify the ability of the chamber clearance. The formation of clusters in the ablated plume in a laser fusion reactor is evaluated by a new model based on Luk’yanchuck, Zeldovich-Raizer model\cite{3}. A new model is written for plane symmetry with any profiles.
2. Stopping Power in High Z and Low Temperature Plasmas

A new model on stopping power in high Z and low temperature plasmas has been developed in this study. Stopping power due to free electrons is obtained by dielectric functions[4], and stopping power due to bound electrons is obtained by binary-encounter model[5]. Resonance electrons behave like free electrons due to physical phenomena. Resonance electrons are obtained by functions of binding energy, population, and energy of incident charged particles. Fig. 1 shows stopping power of $\alpha$ particles in lead as a function of particle energy.

![Stopping power of $\alpha$ particles in lead as a function of particle energy.](image)

3. Ablation Depth and Profiles of a Plume produced by Ablation

I have estimated characteristics of a plume produced by ablation at a distance of 3 m from a target for the case of KOYO-fast. Fig. 2 shows ablation depth as a function of time. As shown in Fig. 2, the effect due to $\alpha$ particles is dominant for determination of ablation depth for this case. Note that, when heating laser is irradiated on target, I set time = 0.

![Ablation depth as a function of time.](image)
Fig. 3 shows density, temperature and velocity profiles of a plume at time = 595 ns, and Fig. 4 shows those at time = 2000 ns. Note that at the time=595 ns, main part of debris from burning target to liquid wall finished and at the time=2000 ns, almost of all debris from burning target to liquid wall finished. As shown in Fig. 3 and Fig. 4, a plume produced by ablation moves with velocities of a few km/s. Temperature in Fig. 4 is good agreement with experimental results[6].

Note that I assumed only vapor leaves the surface. There was no consideration of the possibility of liquid ejection because of its large surface tension effects of liquid lead. In future work, I’ll estimate the surface tension effects of liquid lead quantitatively.

![Fig. 3 Density, temperature and velocity profiles of a plume at time = 595 ns.](image1)

![Fig. 4 Density, temperature and velocity profiles of a plume at time = 2000 ns.](image2)
4. Clusterization in a Plume with Hydrodynamic Motion

Fig. 5 shows profile of radius of clusters and profile of number density of clusters obtained by simulation using DECORE-condensation. When a vapor plume leaves the surface, condensation of a plume starts because of expansion cooling. When the particle number density in a plume becomes sufficiently small, condensation will stop because there is no collision in the plume. Therefore, condensation process is very sensitive to temperature profile and density profile. This result is in good agreement with experimental results[6]. As shown in Fig. 5, radius of clusters in a plume is mainly from 25 nm to 35 nm.

![Fig. 5 Profile of radius of clusters and profile of number density of clusters](image)

In future work, I would like to compare simulation results with experimental results in detail.

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