Response of the first wetted wall of an IFE reactor chamber to the energy release from a direct-drive DT capsule

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Response of the first wetted wall of an IFE reactor chamber to the energy release from a direct-drive DT capsule

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Abstract. Radiation hydrodynamics 1D simulations were performed with two concurrent codes, DEIRA and RAMPHY. The DEIRA code was used for DT capsule implosion and burn, and the RAMPHY code was used for computation of X-ray and fast ions deposition in the first wall liquid film of the reactor chamber. The simulations were run for 740 MJ direct drive DT capsule and Pb thin liquid wall reactor chamber of 10 m diameter. Temporal profiles for DT capsule leaking power of X-rays, neutrons and fast ^{4}He ions were obtained and spatial profiles of the liquid film flow parameter were computed and analyzed.

Keywords: Laser fusion reactor, radiation hydrodynamics, DT burn, liquid film response
PACS: 52.57.-z; 52.55.Pi; 28.52.Cx

INTRODUCTION

An attractive option for Inertial Fusion Energy reactor design is based on a chamber with a wetted first wall. There are a number of projects for this design option, e.g. Prometheus-L [1], Koyo-F [2], developed earlier. The major advantage of the wetted wall design is a replenishment of ablated liquid film in a single shot cycle while the essential issue is a recovery of dispersed liquid phase from the reactor chamber volume. Hydrodynamics of the reactor chamber is determined by the impact of X-ray radiation and fast ions on the liquid film, neutron deposition in the blanket and debris propagation through the cavity atmosphere. The ablation of the liquid film have been studied in [3], under X-ray deposition, and in [4], under fast ions deposition. In both studies a special emphasis was made on the aerosol formation and evolution.

In this paper the hydrodynamics is simulated in the reactor chamber of 10 m equatorial diameter with 2 mm Pb liquid film at the first wall. Prior the shot the temperature of the Pb liquid film is taken as 823 K, with saturated vapor pressure of 0.01 Pa. The 740 MJ DT capsule corresponds to the conventional direct drive target design [5]. The computation of DT capsule implosion and burn starts from the moment of maximum implosion velocity of 300 km/s, achieved by a bare DT shell at the end of the ablative acceleration stage, with a fixed value of the entropy parameter α=2 [6]. This paper examines the two initial stages of the reactor chamber hydrodynamics: (a) DT capsule implosion and burn and (b) X-ray and fast ions

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deposition in the liquid film. In order to assess the effects of these factors the 1-D radiation hydrodynamics simulation codes DEIRA [7] and RAMPHY [8] were run.

DIRECT DRIVE DT TARGET OUTPUT SIMULATION

In order to assess the target output and to determine the temporal profiles of leaking power for photons, neutrons and fast ions, as well as the fluid profiles parameters in the burned fireball (debris), the 1-D radiation hydrodynamics code DEIRA was used. The features of the DEIRA code include electron and ion thermal conduction and temperatures relaxation, ion viscosity, electron and ion heating rates by thermonuclear neutrons, radiation diffusion and relaxation between electron and radiation temperatures, diffusion and relaxation of energy of fast fusion products, mean Rosseland and Planckian opacities, two-temperature equations of state, thermonuclear burn (DT, DD, DHe^3) without in-flight reactions, and applied energy sources: time- and energy dependent ions, electrons and X-rays. DEIRA have been used to elaborate heavy ion IFE target design [9] and for ignition energy scaling of laser IFC direct drive targets [6]. In article [6] DEIRA simulations were performed for an imploding and burning of DT capsule from the state of maximum implosion velocity which is generated by the end of ablative acceleration stage.

The maximum implosion velocity state is taken in the present computations for formulation of initial conditions. It is characterized by a uniform velocity of 300 km/s and dynamically consistent profiles of pressure and temperature. In Fig.1a the geometry of precompressed capsule and radial pressure and temperature profiles are

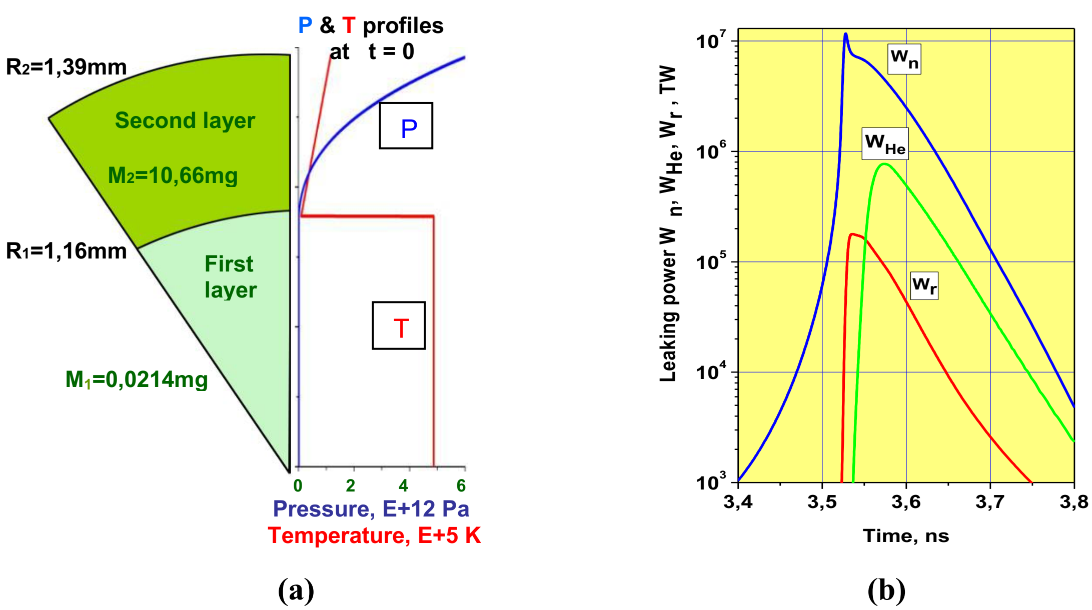
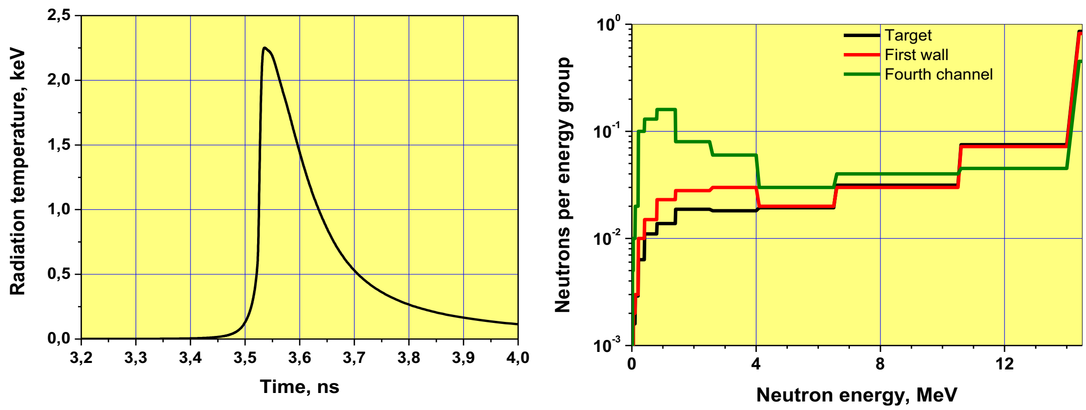


FIGURE 1. (a) Initial geometry and radial pressure *P* and temperature *T* profiles for 740 MJ direct drive DT capsule in the maximum implosion velocity state. (b) Temporal profiles of the leaking power X-rays W_r, neutrons W_n and fast ^{4}He ions W_{He}.

presented. The density profile is a given selfsimilar function of the fractional radius, and pressure is related to density by the adiabatic low with the index α=2. In this state the capsule is compressed to about one quarter of initial diameter and the first shock has reached the center.

The simulation presents the further process of capsule implosion. In 3.53 ns the maximum capsule compression occurs which is accompanied by maximum burn rate. The minimum radius is equal to 0.733mm. In Fig.1b the leaking power of major burn products, i.e. X-rays, neutrons and fast ^{4}He ions, are plotted. The energy partitioning is as follows: X-rays 9.8 MJ, neutrons 535 MJ and fast ^{4}He ions 49 MJ. The time-dependence of the X-ray temperature of the fireball surface is presented in Fig. 2a.



(a) (b)

FIGURE 2. (a) X-ray temperature of the fireball surface. (b) The neutron spectra leaking the DT capsule (Target line) and the liquid first wall (First wall line).

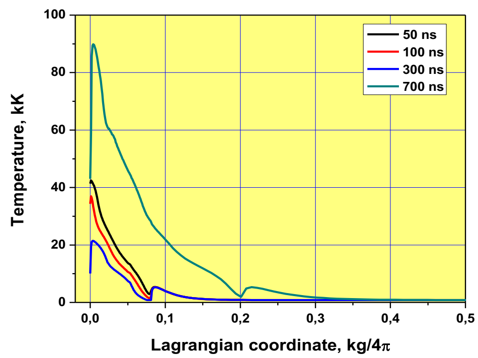
The DT fuel burn is virtually ended at 4.16 ns. The fuel burn-out amounts to 0.18. To this moment the fireball expansion velocity reaches $1.08 \cdot 10^4$ km/s and its radius increases to 6.47 nm.

For evaluation of neutron energy deposition in the liquid film, it was supposed that neutron irradiation is spherically symmetrical. The neutron spectrum is assessed with the use of MCNP code [10]. Fig. 2b shows the neutron spectra leaking the DT capsule and the liquid first wall. The effect of a softening of the neutron spectrum due to inelastic scattering and multiplication appears. Behind the liquid first wall the average neutron energy is equal to 12.2 MeV.

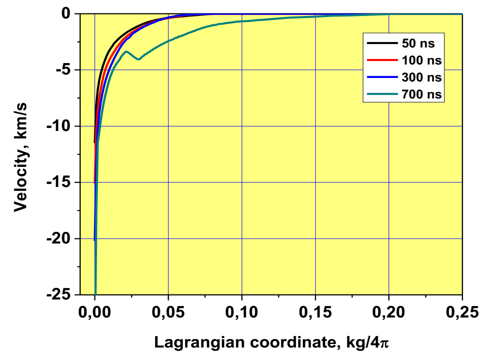
FIRST WALL LIQUID FILM RESPONSE TO THE FUSION PRODUCTS

The response of the liquid film to X-rays, neutrons and fast ^{4}He ions is simulated with the RAMPHY code. RAMPHY is 1-D 2-T radiation hydrodynamics code with the emphasis on matter vaporization and ionization. This code describes plasma thermal conduction and viscosity, radiation diffusion and relaxation between plasma and radiation temperatures, mean Rosseland and Planckian opacities, neutron diffusion and heating (MCNP), condensed matter strength and spallation, wide-range equation of state, phase transitions and ionization, applied energy sources: X-ray, neutron and fast ions volumetric energy deposition.

The loading of the first wall liquid film appears from the following sequence of events: X-ray arrival (ends at 50 ns), neutrons arrival (100 ns), fast ^{4}He ions arrival (700 ns). Before the shot, the lead film has the temperature of 823 K and the density of 10.55 g/cm3. In Fig. 3a the temperature profiles in Lagrangian coordinate are drawn.



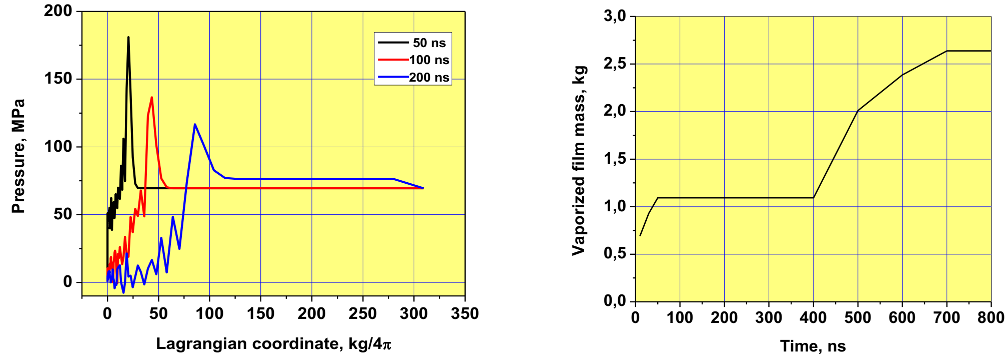
(a)



(b)

Figure 3. (a) The temperature profiles in evaporating lead film with respect to Lagrangian coordinate. The time moments are shown in the legend. (b) The velocity profiles in evaporating lead film with respect to Lagrangian coordinate.

The initial radius of the spherical reactor cavity is equal to 5 m. The X-ray heating is presented by the 50 ns line. The small kink is localized at the vaporization front. In the time interval 50-400 ns the vapor is cooled down. The neutron deposition taking place at about 100 ns is not visualized since the generated temperature rise amounts to about 10 K. The fast ^{4}He ions deposition occurs in the time interval 400-700 ns. The resulting heating of vapor and liquid is presented by the 700 ns line. The maximum temperature rises to 90 kK. The velocity distributions are shown in Fig. 3b. The vapor layer expands continuously while reaching the surface velocity of 11 km/s under the X-ray heating and 32 km/s under the fast ^{4}He ions heating. The pressure profiles are presented in Fig. 4a. At time moment of 50 ns, when the X-ray deposition has been



(a) (b)

Figure 4. (a) The velocity profiles in the lead film with respect to Lagrangian coordinate for the time moments shown in the legend. (b) The time dependence of evaporated mass for the spherical reactor cavity with 5 m radius.

accomplished, the shock pulse is formed. The shock is traveling across the liquid film, spreading in the width and reducing in the intensity. The pulsations at the release paths of the pressure profiles may be attributed to the rough flow discretization. The deposition the fast ^{4}He ions does not lead to substantial pressure rise because of the large width of the pulse. The time dependence of evaporated mass for the spherical reactor cavity with 5 m radius is drawn in Fig. 4b. In the time interval between the X-ray heating end (50 ns) and the fast ^{4}He ions deposition start there is no the vaporization of the film.

CONCLUDING REMARKS

Scaling of the direct drive target threat fluxes based on 1-D simulation performed for a certain DT capsule configuration characterized by the state of maximum explosion velocity provides all necessary data for assessment of the reactor chamber design. For the 740 MJ DT target the temporal profiles of X-ray, neutron and fast ions power are provided. In addition, the data on spatial distributions of the debris flow parameters are available by the end of the fuel burn. These data are to be used for the simulation of the debris fireball expansion in the reactor chamber atmosphere. The response of the first wetted wall results in the stepwise ablation of the lead film. The essential issue to be solved for the effective reactor chamber operation is the formation and removal of the aerosol.

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REFERENCES

1. "Inertial Fusion Energy Reactor Design Studies, Prometheus-l and Prometheus-H", Final Report, DOE/ER-54101, MDC 92E0008, U.S. Department of Energy, Vol. II (Mar. 1992).
2. T. Norimatsu, *et al*, "Conceptual Design of Laser Fusion Reactor KOYO-F Based on Fast Ignition Scheme", *Proc. 21st IAEA Fusion Energy Conf.*, Chengdu, China, 2006, IAEA/FT/P5-39, IAEA.
3. T. Norimatsu, *et al*, "Stagnation of Ablated Metal Vapor in Laser Fusion Reactor with Liquid Wall", *Proc. 23rd IAEA Fusion Energy Conf.*, Daejon, Korea Rep of, 2010, IAEA/IFE/P6-21. IAEA.
4. F. Najmabadi, A. R. Raffray and the ARIES-IFE Team, *Fusion Science and Technology*, **46**, 401-416 (2004).
5. J. D. Sethian *et al*, *IEEE Trans. on Plasma Science*, **38**, 690-703 (2010).
6. M.M. Basko, J. Johner, *Nuclear Fusion*, **38**, 1779-1788 (1998).
7. M. M. Basko, "DEIRA 1D-3T Hydrodynamic Code for Simulating ICF Targets Driven by Fast Ion Beams", Istitute for Theoretical and Experimental Physics, 2001.
8. M. M. Basko, S. A. Medin, Yu. N. Orlov, V. M. Suslin, "Through Simulation of Thermonuclear Fusion and Plasma Expansion in HIF Reactor Chamber", KIAM Preprint, No.18, 2010 (In Russian).
9. M. M. Basko, M. D. Churazov , A. G. Aksenov, *Laser and Particle Beams*, **20**, 411–414 (2002).
10. GROUP-6, "MCNP—A General Monte Carlo Code for Neutron and Photon Transport", LA-7396-m revised, Los Alamos National Laboratory, April 1981.