

Numerical Studies of Indirect-Drive ICF Targets for Z-pinch Facility

Laurent Jacquet

CEA/DAM-Ile-de-France, BP 12, F-91680 Bruyères-le-Châtel, France

With Z-pinch machines it is possible to convert the stored electrical energy in the accelerator into high temperature plasmas that radiate as soft X-ray sources. As a result of recent improvements in the technology of fast pulsed electrical power and load design, these sources are now powerful enough to be of great interest for fusion applications. Pulsed power is expected to be more efficient in energy conversion and less costly than the laser approach. So, Z-pinch facilities could be an attractive alternative to lasers to achieve controlled fusion.

In this paper we describe first designs of capsules adapted to a future big pulsed power facility: peak value of the current driven in pinch loads close to 60 MA, soft X-ray yields of 15-20 MJ with powers exceeding 1000 TW. These figures have been extrapolated [1] from the experimental results obtained with the machine Z of Sandia National Laboratory which currently yields radiation powers as high as 200 TW [2]. The studies presented hereafter are restricted to the so-called "dynamic holraum" concept [3] where the capsules are sit in low-density plastic foam at the center of the imploding Z-pinch. This method is expected to work since recent experiments have shown it is now possible to make Z-pinches that remain uniform long enough to drive a DT pellet [4], [5].

At first, we have performed 1D simulations of an un-doped beryllium ablator, cryogenic DT capsule with a radius equal to 0.25 cm; the thickness of the ablator is 0.3 mm, the inner radius and the mass of the DT solid are respectively 0.2 cm and 2.35 mg. The center of the capsule is filled with about 10 μ g of very low density DT gas. The boundary conditions are an incoming radiation flux and a pressure at the outer surface of the capsule which are obtained from a 2D simulation of the full Z-pinch load [6]. Its starting configuration consists of a 0.01 g/cc doped SiO₂ liner (2 cm in outer radius and 2 cm in length) and a 5 mg/cc central CH foam (1.7 cm in outer radius and 2 cm in length), the capsule being located on the axis inside the CH foam. An other possible experimental arrangement could be a tungsten liner impacting a central foam.

As a result of the ablation process, a first shock wave is launched in the target and passes through the fuel. Then two other converging shocks and a series of compression waves are generated by the interaction of the rarefaction waves which propagate outward and the ablation front. These shocks compress the DT and coalesce inside the DT gas. Just before the focalisation time the implosion velocities exceed 3×10^7 cm/s near the center of the target. After focalisation a small fraction of the DT is heated to ignition level temperatures. From this hot spot (about $30\mu\text{g}$) a thermonuclear burn wave propagates outward into the surrounding fuel. For an 1.5 MJ energy absorbed from the driver, we get with this target a thermonuclear yield of 390 MJ and a gain close to 270.

The damaging effects due to the instabilities at the ablation front of ICF capsules can be limited, under some conditions, by increasing the opacity of the ablator [7]. Therefore we have studied targets for which a part of the ablator located close by the DT is made of beryllium doped with 1 % of copper atoms. The simulations indicate that the timing of the shocks that travel through the DT is modified by varying the thickness of the doped beryllium shell. In some cases, when the thickness of the un-doped and doped shells are approximately equal, the stand-off times between the arrival of the three main converging shocks at the interface between the hot spot and the main fuel layer are increased. Consequently, the implosion process is less effective, as the velocities in the central part of the DT remain less than 2.4×10^7 cm/s and the given internal energy is no longer high enough to the ignition can occur. The results also show that a full doped ablator target has better performances than the standard target since its yield reaches 440 MJ.

The final section of this paper is devoted to a first insight into a new concept of targets in which a mass fraction of the outer cryogenic DT is replaced by a shell of heavy material, for instance gold. Various thickness of the heavy shell have been envisioned with the same solid DT inner radius and ablator thickness as in the starting target configuration. For this former one the change in fuel entropy is mainly due to the first shock formed in the ablator. When this shock hits and passes across the thin heavy shell, several shocks in rapid succession are generated which give a higher density jump but a smaller entropy change for the DT than a single shock. So, due to the hydrodynamic effect of the gold shell, less entropy but more internal energy is deposited in the DT during compression. As the heavy shell mass increases, the thermonuclear yield decreases but the burning efficiency of the fuel is improved. Another main result is that these targets appear more robust since they ignite for all the ablator (un-doped or partially doped) configurations.

All the 1D simulations of this paper have been done with a lagrangian hydro-code including distinct electron and ion temperatures, non equilibrium multigroup radiation transport and multigroup charged-particle transport. The hydrodynamic instabilities, at the ablation front but also at the interface between the gold shell and the fuel for the last target configuration, have not been taken into account. To estimate the variations in capsule performances due to these effects could be the object of further work.

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