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**Double-Shell Target Designs for
The Los Alamos Scientific Laboratory
Eight-Beam Laser System**

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DOUBLE-SHELL TARGET DESIGNS FOR
THE LOS ALAMOS SCIENTIFIC LABORATORY
EIGHT-BEAM LASER SYSTEM

by

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ABSTRACT

We investigate two double-pusher laser fusion targets, one that incorporates an outer exploding pusher shell and another that uses velocity multiplication. Specific designs are presented for the Los Alamos Scientific Laboratory Eight-Beam Laser System.

I. INTRODUCTION

Laser-driven pellets with multiple shells have been the subject of considerable attention¹⁻³ in the laser fusion community. In this report we elaborate on a modification⁴ of the conventional, velocity multiplying double-shell targets.¹⁻³ Specifically, we consider the case where the outer shell is thin enough so that the suprathermal electrons heat it to an isotherm. Of course, in this mode the outer shell behaves as the well-known laser-driven exploding pusher microballoon.⁵⁻⁸ In addition, we evaluate a velocity multiplying double-shell¹⁻³ target design that has a small DT mass typically in the range of several nanograms.

II. DOUBLE-SHELL EXPLODING PUSHER

Figure 1 depicts a two-shell laser-driven target with the outer shell in the exploding pusher mode. This type of target has been previously discussed in Ref. [4], thus, this report is intended to expand on the basic idea and to present a specific target design for the Los Alamos Scientific Laboratory (LASL)

ADVANTAGES

1. DRIVING SHELL BEHAVES AS A CONVENTIONAL EXPLODING PUSHER:
 - (a) WELL UNDERSTOOD
 - (b) EASILY RELATABLE TO PREVIOUS DESIGNS
2. EXPLODING PUSHER SHELL TRANSFERS ENERGY TO INNER ABLATIVE PUSHER WITH HIGH SYMMETRY

DISADVANTAGE

1. RELATIVELY POOR SHELL COUPLING

Fig. 1.

Double-shell exploding pusher target.

Eight Beam Laser. The basic motivation for studying this design comes from the observation that laser-driven exploding pusher shells implode with a high degree of symmetry as a result of their isothermal character. Associated with this advantage is the obvious disadvantage that the exploding pusher shell couples poorly to the inner shell, which is to be driven by electron conduction. In this report we consider (1) the advantage of this target by comparing one- and two-dimensional LASNEX⁹⁻¹⁰ simulations and (2) the disadvantage (poor coupling) by actually calculating the performance of the proposed target. It is concluded that in the laser energy range of interest the disadvantage is not particularly great, especially when symmetry problems inherent in velocity multiplying, ablatively driven targets are taken into account.

Further comparison of the proposed target with exploding pusher and conventional double-shell targets is given in Fig. 2. In addition to the symmetry

Fig. 2.

Comparison of (1) exploding pusher, (2) double-shell exploding pusher, and (3) conventional double-shell laser fusion targets.

advantage discussed above it is found that specific designs of the double-shell exploding pusher (DSEP) target are:

- (1) relatively insensitive to the fill pressure between the exploding pusher and electron driven shells,
- (2) relatively insensitive to 50% variations in the superthermal electron temperature,
- (3) relatively insensitive to variations in shell wall thicknesses,
- (4) amenable to small aspect ratio inner ablatively driven shell,
- (5) can be optimized for relatively low-DT gas fills near 75 atm,
- (6) easier to fabricate than some conventional double-shell targets because the support for the inner shell may be detached from the outer exploding pusher shell as the fill between these shells can vary between 1 atm and vacuum without significantly degrading target neutron yield.

Several of the advantages are clearly related to the high symmetry inherent in the DSEP target. Finally, we add that the relative insensitivity of the

design to various parameters and two-dimensional effects implies that this target is probably (1) relatively easy to construct and (2) accurately predicted by the present numerical simulations.

A specific DSEP target design is shown in Fig. 3. For a laser pulse that rises linearly to 20 TW in 200 ps and falls linearly to 0 TW at 0.8 ns, a maximum neutron yield of approximately 6×10^9 is calculated with the suprathermal electron parameter, α ,¹¹ taken as -20. In addition, a " ρR " of 0.008 g/cm^2 and an " $n\tau$ " of approximately 10^{14} are achieved. These parameters are not observed to be strongly influenced by varying α between -8 and -30.

Fig. 3.

A typical DSEP design.

The insensitivity of this design to α is inherent in the exploding pusher scheme.

The number of neutrons, N_n , produced by a similar DSEP target is found to scale with greater than the third power of P_L , the peak laser power. This behavior is displayed in Fig. 4 for a design, operating at 20 TW similar to that in Fig. 3, but with an aluminum wall thickness of $1.3 \mu\text{m}$ and a gold wall

Fig. 4.

Neutron yield as a function of peak laser power for targets optimized at 10 TW and 20 TW.

thickness of $4.1 \mu\text{m}$. In Fig. 4, a separate design, optimized for 10 TW, is seen to give similar neutron yields. This 10-TW design has a gold thickness, an aluminum thickness, and a DT fill of $3.2 \mu\text{m}$, $1.5 \mu\text{m}$, and 75 atm, respectively.

The general behavior of the DSEP target for a design similar to that in Fig. 3 with a peak power of 20 TW is summarized in Figs. 5, 6, and 7. Figure 5 depicts the radius of the gold-DT interface as a function of time with the instantaneous implosion velocity given at two specific times. Figure 6 illustrates the average ion, electron, and radiation temperatures in the DT gas as a function of time. Finally, Fig. 7 represents the time history of the DT pressure P , the average DT density ρ , and the neutron production.

The insensitivity of the DSEP target to wall thickness of the pusher shells is illustrated by Figs. 8 and 9. The one-dimensional LASNEX simulations

Fig. 5.

Gold-DT radius as a function of time.

presented in these figures indicated that large variations in material thicknesses have only minor influence on neutron production. This is in definite contrast to the conventional double-shell targets, which usually are very finely tuned with regard to wall thicknesses. In addition, Fig. 8 illustrates that

Fig. 6.

Average ion, electron, and radiation temperatures in the DT gas as a function of time.

the shell (ablative shell) thickness may be varied to give aspect ratios from 12 to 25 without causing large fluctuations in the neutron yield. In Fig. 8, the three arrows indicate the thickness corresponding to aspect ratios of 12, 15, and 20.

Fig. 7.

Time histories of the DT gas pressure, density, and neutron production.

Fig. 8.

Neutron yield as a function of gold shell thickness.

In Fig. 9, the solid curve was calculated with a minimum electron temperature, $T_e^{\min}$, for partial ionization physics of 10 eV. As a check on the impact of $T_e^{\min}$ on the DSEP design, a separate calculation was performed with $T_e^{\min} = 1$ keV. As shown in Fig. 9, the neutron yield does not depend sensitively on $T_e^{\min}$ or on the aluminum thickness for the DSEP target.

Fig. 9.

Neutron yield as a function of aluminum shell thickness.

In addition to the small aspect ratios needed in the DSEP targets, LASNEX simulations indicated that the two-dimensional effects do not seriously degrade the neutron yield. In fact, two-dimensional LASNEX simulations predict reductions in neutron production by only a factor of 0.3 for a 10 to 1 pole-to-equator illumination asymmetry. In many standard, double-shell, velocity multiplying targets, a 10-to-1 illumination asymmetry is sufficient to drastically reduce the neutron yield.¹²

Finally, we note that the absorption values for CO_2 laser light used in this study were taken to be the plane slab values^{13,14} because the focal spot for the LASL Eight-Beam Laser System is predicted to be smaller than the 320- μm diameter of the DSEP target discussed above. The absorption fraction has been taken as 40%; however, variations from 30% to 50% indicate only a factor of 5 change in the neutron yield.

In summary, the basic idea incorporated in the target design of Ref. [4] has been applied to a specific target design for the LASL Eight-Beam Laser System. It is found that the DSEP is predicted by LASNEX simulations to yield approximately 5×10^9 neutrons and to achieve densities in excess of 70X solid DT density. Furthermore, the design is relatively insensitive to various design parameters and two-dimensional effects associated with laser illumination asymmetry.

III. LOW FUEL-MASS DESIGN

The primary reasons for studying a POLARIS design with a low fuel mass are to achieve high fuel density and large fractional burnup of the fuel. In optimizing a design with the above goals in mind, it is necessary to evaluate the effect of:

- A. Preheat by suprathermal electrons and photons,
- B. Target sensitivity to laser illumination symmetry,
- C. Sensitivity of target to changing material radii,
- D. Varying cushion mass on target performance,
- E. Varying the fuel mass,
- F. Replacing a DT ice layer with a DT gas, and changing the laser power.

All of these aspects are not addressed here in complete detail; however, a separate report is planned that contains full details. In this study it is found that the suprathermal electron preheat is a major factor in the design. Specifically, a high-Z outer pusher leads to more scattering of suprathermal electrons and then less preheat. In addition, high-Z materials are necessary for preventing photon preheat. On the other hand, high-Z materials are usually accompanied with high densities. Thus, in an attempt to maintain small aspect ratios and high-Z materials, the total mass of the shell in question becomes too large. These considerations lead one to an outer pusher of a low-Z material with a high-Z impurity. In the designs discussed herein this material is CHOW. [By atom per cent, CHOW's composition is 32.3% carbon (C), 64.6% hydrogen (H), 2.2% oxygen (O), and 0.88% tungsten (W).]

Figure 10 depicts a double-shell velocity multiplying target with a low fuel mass (2.7 ng) and an outer pusher of CHOW. For this design a factor of 3 variation in the cushion mass has less than 10% effect on the neutron

Fig. 10.

A typical double-shell, velocity multiplying target design with a low fuel mass.

Fig. 11.

Plot of radii as a function of time for the design.

yield. In addition, studies in which we replace the layer of DT ice by DT gas filling the entire inner volume, indicate the peak ion temperature and neutron yield are reduced by approximately 20%. In contrast, the peak density is reduced by about a factor of 3 upon replacing DT ice with DT gas.

The design in Fig. 10 is matched to a laser pulse that rises linearly from 0 TW to 10 TW in 200 ps and then falls linearly to 0 TW at 1 ns. In addition, we have (1) taken α , the ratio of the suprathermal electron temperature to background temperature, to be 20 and (2) used the formulation of Ref.[11]. For these conditions, the target of Fig. 10 achieves a peak density of $\sim 30 \text{ g/cm}^3$ (150X solid density), a peak ion temperature in the DT fuel to 620 keV, and a neutron yield of 2×10^7 . These values are obtained without finely tuning the target, and it is therefore felt that they are modest but sound results within the context of one-dimensional calculations. For example, this design is relatively insensitive to the thickness of the CHOW pusher—a 10- μm variation in the thickness leads to only a 40% reduction in the neutron yield.

Finally, we note that the positions of the various shell interfaces as a function of time are shown in Fig. 11.

It is difficult to assess the complete role of illumination asymmetry in the low fuel-mass target. The results obtained in several LASNEX⁹⁻¹⁰ simulations suggest that (a) the peak density can be degraded by a factor of 2 or more (from the one-dimensional result) and (b) the peak ion temperature can be reduced by a larger factor. Figure 12 illustrates the type of asymmetry in implosion hydrodynamics that can result from a large asymmetry in laser illumination. The conclusion of our two-dimensional study is that illumination asymmetry must be kept to a minimum if good performance is to be achieved with the low fuel-mass target. However, we consider this to be largely an experimental question, which can only be resolved in the laboratory.

In summary, it is found that a low fuel-mass velocity multiplying target (POLARIS B) can produce nearly 200X solid density for the Eight Beam Laser parameters when the laser illumination is highly symmetrical. The exact role of illumination asymmetry is an uncertainty that must be resolved empirically.

Fig. 12.

Two-dimensional velocity multiplying target design with a large illumination asymmetry.

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