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TARGETS FOR LASER AND ION BEAM DRIVERS*

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ABSTRACT

At the two previous heavy ion fusion symposia, researchers from Livermore presented their best estimates of target energy gain. The results presented at Tokyo differed significantly from those presented at Darmstadt. The Livermore estimates were again revised for this symposium. The new estimates are given in an accompanying paper by Lindl et al. and in additional detail in this paper. The new estimates are similar to the results presented at Darmstadt. The implications of the new results are discussed.

INTRODUCTION

Recent results on targets for laser and ion beam drivers were reported by J. D. Lindl on the first day of this Symposium.¹ Lindl's talk generated some discussion during the remaining days of the Symposium because:

1. The new Livermore gain curves for lasers and ions are lower than the Livermore curves presented at the 1984 Symposium in Tokyo.²
2. Lindl emphasized that high target gain requires high irradiance.

The new gain curves were not available in time to be used in the Heavy Ion Fusion Systems Assessment (HIFSA),³ which was one of the main topics reported at the Symposium. It is not surprising that this situation has already led to discussion regarding the validity of the HIFSA Study in light of the new gain curves. The emphasis on high irradiance is interesting and important because high irradiance imposes stringent requirements on the quality of the beam emerging from the driver.

The remainder of this paper gives a discussion of the new gain results and their implications and also some additional discussion on the importance of high irradiance.

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MASTER

ENERGY AND POWER REQUIREMENTS

In Refs. 1 and 2, target gain is given as a function of driver energy and a variable $r^{3/2}R$ where r is focal spot radius (cm) and R is ion range (g/cm²). This representation of gain is an approximation that is valid in a restricted domain of r given by $0.1 \leq rE_D^{-1/3} \leq 0.2$ where E_D is driver energy (MJ). To a poorer approximation, the domain of applicability may be extended to $rE_D^{-1/3} \leq 0.35$. To eliminate this approximation and restriction gain must be given as a function of the three independent variables E_D , r , and R . Figure 1 gives new gain curves as a function of these three variables. These curves are based on the same calculations as those in Lindl et al.¹

Fig. 1. Target gain as a function of driver energy for a variety of focal spot radii and ion ranges.

The peak power required by the targets is given in Fig. 2. The results given in these figures are based on single-shell targets. The targets must be illuminated from two sides, and they require an accurately shaped pulse. Double-shell targets have lower power requirements,² but the physics uncertainties are larger and target fabrication is more difficult. The Livermore curves for double-shell targets have not been revised.

Fig. 2. Peak power requirement as a function of driver energy for a variety of focal spot radii and ion ranges.

IMPLICATIONS

In order to determine the implications of the new gain results for the economics of heavy ion fusion, the economic analysis presented at the Symposium⁴ was redone by Wayne Meier using the new gain curves. The cost of electricity increased slightly less than 10%.⁵ Meier's analysis fixed the product $r^{3/2}R$ at 0.02; the HIFSA study did not fix $r^{3/2}R$. Because of this additional flexibility, the HIFSA model may be even less sensitive to gain variations than the Meier model. In any case it would be interesting to include the new gain results in future HIFSA studies.

There was also some concern about the implications of the new gain results for the HIBALL studies^{6,7}. The HIBALL target and the Livermore targets on which Fig. 1 is based are very different. No work has been done indicating that the HIBALL target gain should be revised. It is interesting to note, however, that the curves in Fig. 1 give gains close to the HIBALL value. HIBALL-I used a gain of about 80 at 4.8 MJ. The ion kinetic energy of the HIBALL driver corresponds to a range of roughly 0.1 g/cm² in hot, low-Z material. At 5 MJ and 0.1 g/cm², Fig. 1 gives gains from 10 to 70 for r between 0.4 and 0.2 cm. Since target gain increases rapidly with increasing driver energy, it is likely that HIBALL could be redesigned with a slightly higher driver energy if the Livermore gain estimates were adopted. The economic consequences would probably be small--at least if the focal spot radius could be held to ≤ 0.3 cm.

It is also interesting to note that the results in Ref. 1 and Fig. 1 are very close to the Livermore results presented at the 1982 Symposium in Darmstadt.⁸ The variations during the last few years are indicative of the fact that there are still uncertainties in gain predictions. It will be surprising if further research does not lead to further changes. In fact target concepts giving higher gain than Fig. 1 have already been presented at this Symposium by Livermore investigators.^{9,10} These concepts are more speculative than the concept used for Figs. 1 and 2. More work is needed on these and other high-gain target concepts. Other target work has also been presented at this Symposium. The Livermore work has been referenced only because the various Livermore calculations were performed on the same computer code and are thus normalized to each other. Consequently the differences in gain are truly due to differences in design and not differences in codes.

In summary, the curves in Fig. 1 give the current Livermore best estimates of target gain. Additional work on more speculative target concepts may lead to higher estimates in the future.

IRRADIANCE

The need for high irradiance is not new. Consider the following example. Figure 2 gives a power requirement of 400 TW for $E_p = 5$ MJ, $r = 0.3$ cm, and $R = 0.1$ g/cm². For two-sided illumination, the irradiance is 7.1×10^{14} W/cm². Reference 2 gives about 430 TW and 7.6×10^{14} W/cm² for the same E_p , r , and R . Thus, estimates of required irradiance have changed little in recent years. It does seem important, however, to emphasize the rapid decrease in gain (Figs. 1 and 2) with decreasing irradiance (increasing r) particularly for $R \geq 0.05$ g/cm².

LASER TARGETS

The gain curves for lasers have also been revised (Ref. 1). Both gain and irradiance are also issues for lasers. A reduction in gain is more serious for lasers than for accelerators because the lower efficiency of lasers requires higher target gain in order to obtain an acceptably low recirculating power fraction.

Beam quality is an issue for lasers because, in some reactor designs, the final optical elements are placed 30 to 100 m from the target to minimize damage. For some high-gain laser targets, r should be < 1 mm, so that the angular divergence of rays emanating from any point on the surface of the final optical elements must be $< 10^{-5}$ rad. This is an important constraint, particularly for lasers operating at the high average power needed for a power plant. High average power inevitably leads to nonuniform temperature, density, and stress. These nonuniformities will have to be carefully controlled to avoid excessive beam distortion.

CONCLUSIONS

In conclusion, new best-estimate gain curves have been presented at this Symposium. The new results are expected to have little effect on the economics of heavy-ion fusion principally because the high efficiency of accelerators endows heavy ion fusion with a relative insensitivity to modest variations in target performance.

Irradiance remains an important issue for inertial confinement fusion. Since achievable irradiance is closely related to beam emittance, the increased understanding of emittance growth reported at this Symposium is gratifying.

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