Section 2
PROGRESS IN LASER FUSION

2.A Target Designs with Multi-Frequency Irradiation

The high-density compressions needed for ICF pellet implosions will require that the nonuniformities in laser-energy deposition not exceed ~1% rms.[1] Differences in energy deposition can cause some regions of the target to be driven harder than others, resulting in shell deformation and ultimately a reduction of neutron yield. The actual amount of nonuniformity which a pellet implosion can tolerate will depend on the details of the individual target, pulse shape, and laser wavelength being used.

Some variance in energy deposition can be smoothed by lateral thermal transport,[2] while heat is being transported from the region of energy deposition (near the critical surface) to the ablation surface. Long-wavelength laser irradiation can produce substantial amounts of smoothing, because the separation distance, ΔR, between the critical and ablation surfaces increases with wavelength.[3] Nevertheless, short-wavelength irradiation (e.g., 351-nm) is preferred for driving fusion targets, due to its higher absorption and hydrodynamic efficiency.[4] Previous estimates[1] have shown that the smoothing distance, ΔR, achieved by short-wavelength irradiation near the peak of the pulse, should be adequate to smooth the nonuniformities anticipated for ICF reactor illumination.

At the onset of pellet irradiation, the amount of smoothing is expected to be small for all wavelengths; separation between the critical and ablation surfaces is small at this time. One strategy[5] to mitigate this "start-up" problem while retaining the benefits of shorter-wavelength irradiation is to illuminate the pellet initially with a longer wavelength (1054-nm), to establish the pellet atmosphere, and then to change to a shorter wavelength to drive the target. The techniques for irradiating a target with different laser frequencies will not be discussed here, but we note that multi-frequency irradiation can occur naturally by tripling the frequency from Nd:glass lasers.[6] When tripling crystals are optimized to produce blue light (351-nm) at the high-intensity peak of the pulse, the conversion efficiency will be poor at low intensity, resulting in irradiation predominantly with red light (1054-nm) at the start of the pulse.

We have begun one- and two-dimensional computer simulations to determine a pellet's tolerance to imposed irradiation nonuniformities with and without multi-frequency illumination. The numerical simulations were carried out on the cryogenic target shown in Fig. 1. This target is composed of a polyethylene (CH_2) ablator and solid D-T fuel. The pellet was irradiated with the double-Gaussian pulse shown in Fig. 2, containing approximately 30 kJ of energy. The pulse-timing was chosen so that the target reaches the energy break-even point for uniform irradiation at normal incidence. (Note that this is not necessarily an optimal design for 30 kJ and no attempt has been made to examine its hydrodynamic stability.) Numerical simulations were performed for two cases: one in which both pulses of the double-Gaussian pulse were blue and the other for which the first pulse was red and the second blue.

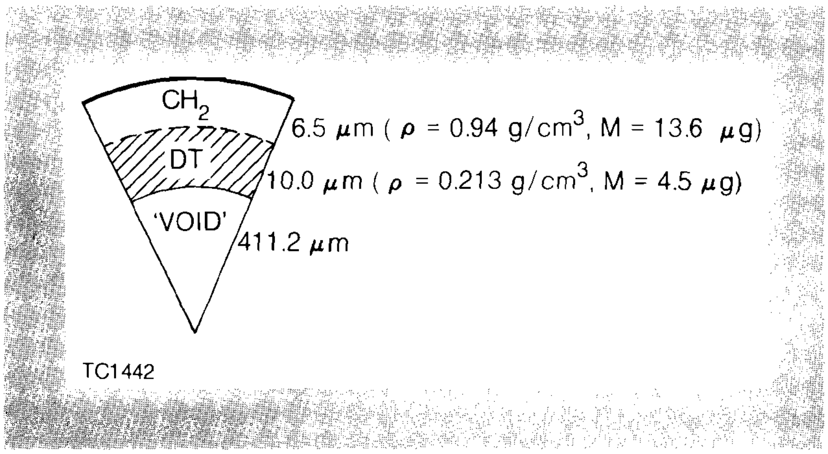

Fig. 1
Cryogenic target used to model shell deformation by nonuniform laser irradiation.

The fractional separation distance, ΔR, between the critical and ablation surfaces is plotted as a function of time during the implosion on Fig. 3 for the two cases considered. This factor, in part, determines the amount of thermal smoothing. The attenuation of the nonuniformity in laser-energy deposition may be expected to vary as $\exp(-\ell\Delta R/R)$ where ℓ is the mode number in a spherical harmonic decomposition of the nonuniformity. (The spatial wavelength λ of the nonuniformity is related to ℓ and the target radius R by: $\lambda = 2\pi R/\ell$.) Previous calculations[1] have shown that a value $\Delta R/R \approx 0.1$ should be adequate for smoothing the nonuniformities characteristic of an ICF-reactor laser configuration; this is because of the high degree of uniformity in laser deposition and the small spatial wavelength of the nonuniformity ($\ell \gtrsim 10$). As seen in Fig. 3, $\Delta R/R = 0.1$ is reached before the peak of

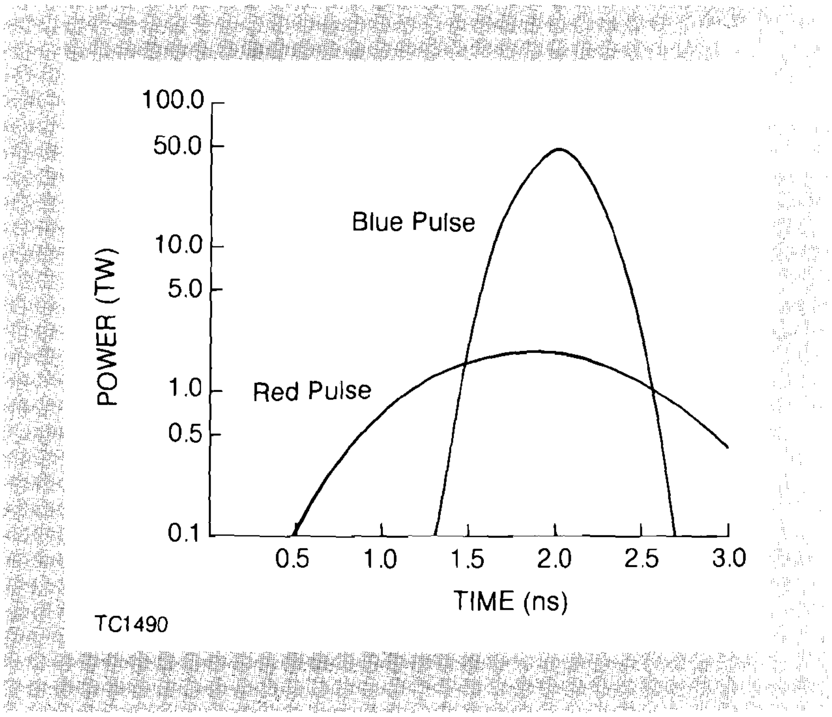

Fig. 2
Double-Gaussian pulse used in the calculations. The effect on the implosion of a red or blue first pulse was examined.

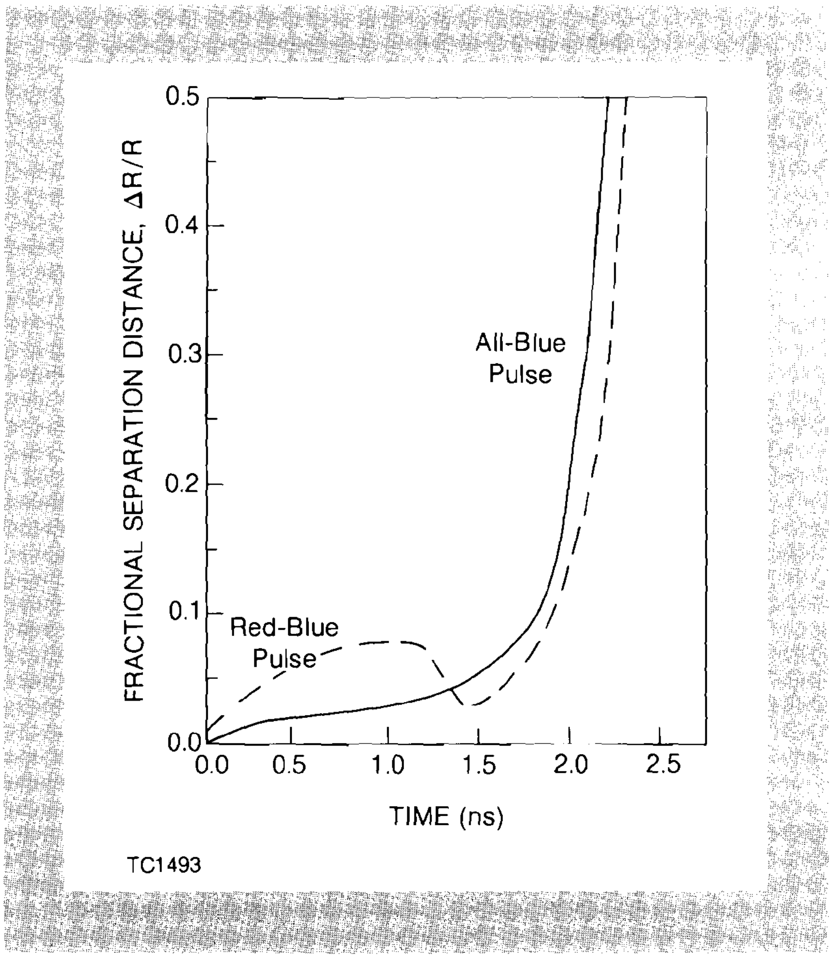

Fig. 3
Calculated smoothing distance between the critical and ablation surfaces as a function of time for the all-blue and red-blue cases. Note the increased smoothing distance for the red-blue combination early in time.

the pulse; thus, most of the laser energy should be absorbed with relatively good smoothing. The large values of $\Delta R/R$ achieved at the peak of the pulse are due to a reduction in target radius during the implosion. At the onset of irradiation, there should be negligible smoothing for the all-blue pulse. Although only a small amount of energy is deposited early in time, it is possible to generate a shock at the ablation surface which will travel through the target and imprint the laser nonuniformity directly on the fuel.

The increased smoothing distance achieved with the red prepulse is evident in Fig. 3. Although the value reached during the first pulse, $\Delta R/R \sim 0.07$, is not large due to the low intensity, it could be adequate for smoothing an $\ell = 10$ nonuniformity by a factor of 2. The decrease in $\Delta R/R$ for the red-blue pulse relative to the all-blue pulse at ~ 1.5 ns is not significant and results from a slight difference in the implosion times.

To examine the effect of laser nonuniformity on the target implosion, two-dimensional simulations were performed with the Lagrangian code *ORCHID* in which an $\ell = 8$ variation was superimposed on the laser power (assuming normal incidence). The peak-to-valley variation of laser intensity was 4%, corresponding to $\sigma_{rms} = 1\%$. The deformation of the shell was measured in terms of the distortion of numerical grid interfaces, $R(\theta)$, at different places in the target, with the rms variation defined as:

$$\delta_{rms} \equiv \frac{1}{\pi} \frac{\int [R^2(\theta) - \langle R \rangle^2]^{1/2} d\theta}{\langle R \rangle}$$

where

$$\langle R \rangle = \frac{1}{\pi} \int R(\theta) d\theta \ .$$

Figure 4 shows how the rms variation of an interface near the center of the fuel changes during the implosion for both the all-blue and the red-blue pulses.

The onset of deformation occurs at the initial shell radius of ~ 400 μm as the laser nonuniformity imprints itself on the target. The deformation then increases by an order of magnitude during the remainder of the implosion. Such a sudden onset of the deformation when the shell first begins to move is similar to results discussed in Ref. 7. As seen, the distortion produced in the target by the red-blue pulse is less by a factor of two.

The reasons why this particular target can tolerate more of the laser nonuniformity with the red-blue combination have not been completely determined. Two factors were observed in the simulations: one was the increased smoothing distance produced by the red prepulse; second, the red light was found to produce a weaker "first shock," resulting in less preheat and less decompression of the fuel. We are currently investigating the influence these two factors have on the target implosion.

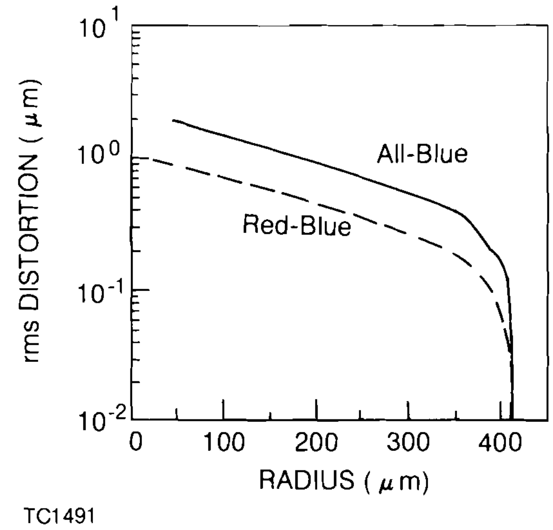

Fig. 4
Growth of target deformation during the implosion. The target can tolerate about a factor of 2 more laser nonuniformity using the red-blue pulse.

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