Section 1
PROGRESS IN LASER FUSION

1.A A Summary of Recent High-Density Experiments on OMEGA

During the first five months of 1987, experiments on OMEGA have concentrated on creating measurable high-density laser-fusion compressions in gas-filled spherical targets. To this end, experimental and theoretical programs have been conducted to address issues key to the successful implosion of ablatively driven, low-aspect-ratio targets. These programs have centered on (a) the characterization of the current level of target illumination uniformity with the up-converted 24 beams of OMEGA; and (b) the performance of a number of scaling experiments on solid and shell targets to correlate experiments with theoretical predictions and determine sensitivity of specific targets to illumination uniformity. These studies have resulted in the characterization of glass shell and low-Z ablator shell target implosions that have demonstrated final compressed fuel densities of ~ 50 times liquid density (XLD), with absorbed laser energies of < 1 kJ. This report describes the most important features and results of these experiments.

Two basic target designs were examined. The first was a glass shell with wall thickness $(\Delta R)_o \sim$ (3–6 μm) and a radius of $(R_o) \sim 100\,\mu$m or 150 μm, filled with D_2 or DT to pressures of 10–100 atm.[1] This type of target is predicted to have a relatively modest in-flight aspect ratio $(R/\Delta R)$ and should stagnate with a wide range of convergence ratios (R_o/R_t), where R_t is the final core radius, depending on gas pressure and shell thickness. It is a good target design to examine potential degradation of target performance due to illumination nonuniformities. The second target design had similar overall size and fuel conditions, but had a target wall of a 3-μm glass pusher, overcoated with various thicknesses of parylene.[2] The addition of a low-Z ablator should reduce the level of radiational fuel preheat, and produce, depending on ablator thickness, a colder (lower isentrope) implosion leading to higher fuel densities.

These targets were irradiated with up to 1.5 kJ of 351-nm laser light from the 24-beam OMEGA facility,[3] in pulses of ~700-ps duration. Estimates of the overall illumination intensity distribution were made from detailed beam-footprint characterization of each of the OMEGA beams. This was done by two independent methods: UV photography of an equivalent target plane (described in the article entitled "High-Power Laser Interferometry" in this issue), and x-ray photography of individual beams focused on solid, spherical high-Z (Au or Cu) targets.[4] The overall level of uniformity, determined from spherical mode decomposition of the intensity distribution, was ~20%; however, this included some microscopic hot-spot structure (~20-μm scale size) having intensities up to three times the nominal intensity. The hot-spot structure has been determined to arise from the integral effects of wave-front nonuniformities imprinted on the beam distribution during propagation through the laser amplifier chain.[5]

A comprehensive set of plasma, x-ray, and nuclear diagnostics was deployed to characterize these implosions, to compare with the predictions of one-dimensional (1-D) and two-dimensional (2-D) hydrodynamic code calculations. Emphasis in these experiments was placed on those diagnostics that provided information on the compressed fuel conditions.[6] The principal diagnostics were neutron dosimetry, neutron time-of-flight spectrometry,[7] shell areal density measurements by neutron activation,[8] x-ray microscopy,[9] and time-resolved x-ray photography.[10] In addition, some estimates of the fuel areal density were obtained from measurements of the secondary-reaction products of D_2-filled targets.[11,12]

Characterization of the laser energy coupling to the target, and its partition to x rays, was in good agreement with the predictions of the 1-D hydrodynamic code *LILAC*, assuming modest (f = 0.06) thermal flux inhibition.[13] The details of the data on absorption and x-ray calorimetry are described in the article entitled "Absorption and Radiation of Energy from Spherically Irradiated Targets" in this issue. The results support the model assumption of predominant inverse-bremsstrahlung absorption, with very low levels ($\sim 10^{-3}$) of superthermal electron generation. Good agreement between measured and predicted values of the absorption for the low-Z ablator targets was also obtained. Reliable x-ray measurements were not obtained for these targets.

X-ray photographic measurements of the glass shell correlated well with *LILAC* predictions of the shell conditions and flight during the implosion. Figure 31.1 provides an illustration of this. Figure 31.1(a) shows a (~2-keV) x-ray microscope image of a glass shell target and its azimuthally averaged line profile with target radius. The x-ray emission from the outer regions of the image, resulting from the hot,

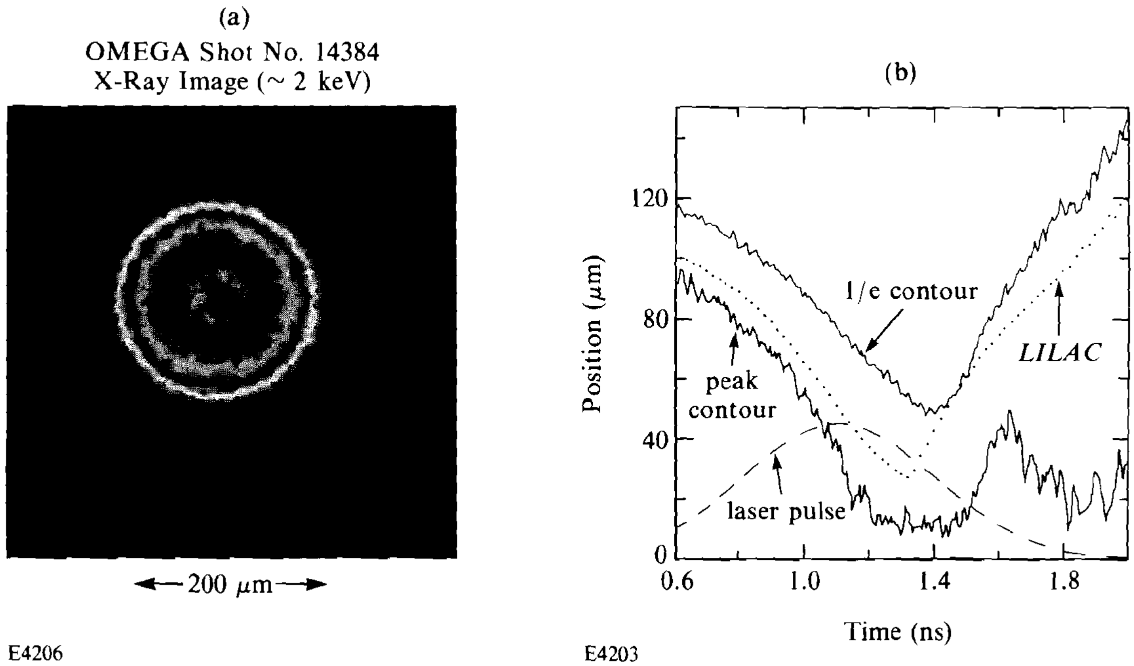

Fig. 31.1
Detailed x-ray photography of an imploding glass shell target. (a) Details of an x-ray microscope image and (b) reduced R-T distribution of x-ray emission acquired with a streak x-ray pinhole camera.

high-density region of the shell during its acceleration, is well modeled by *LILAC*. These measurements support the view that this phase of the implosion is symmetric; the measurements are substantiated by time-correlated[10] x-ray streak photography of the emission. The trajectory of the emission, deduced from digitized streak data, agrees well with 1-D hydrodynamic code predictions,[14] as demonstrated in Fig. 31.1(b). Moreover, there is indirect evidence for integral stagnation of the shell in that a radial minimum exists in the x-ray emission throughout the implosion. However, details of the fuel shell interface are not produced by this diagnostic. It therefore cannot determine the extent, if any, of pollution of the fuel by cold fragments from the inner shell.

This behavior appears to be more complex with the low-*Z* ablator targets. With these targets, there is evidence, both from time-resolved x-ray imaging[14] and time-resolved x-ray line spectroscopy on special signature layer targets,[15] of anomalous early lightup of inner regions of the shell. This phenomenum is most probably associated with intense hot spots in the beam distribution. Its effect on the inner fuel region and the final implosion is not fully understood at this time and is under investigation.

The measured neutron yield for glass shell targets is close to the 1-D hydrodynamic code predictions for low-convergence-ratio targets, as in Fig. 31.2. Since the neutron yield is a sensitive function of the fuel temperature, this approximate agreement indicates that targets that stagnate to fairly large core sizes ($\geq$ 30 μm) maintain good symmetry throughout the implosion. However, Fig. 31.2 shows that as the expected convergence ratio of the target increases, the measured

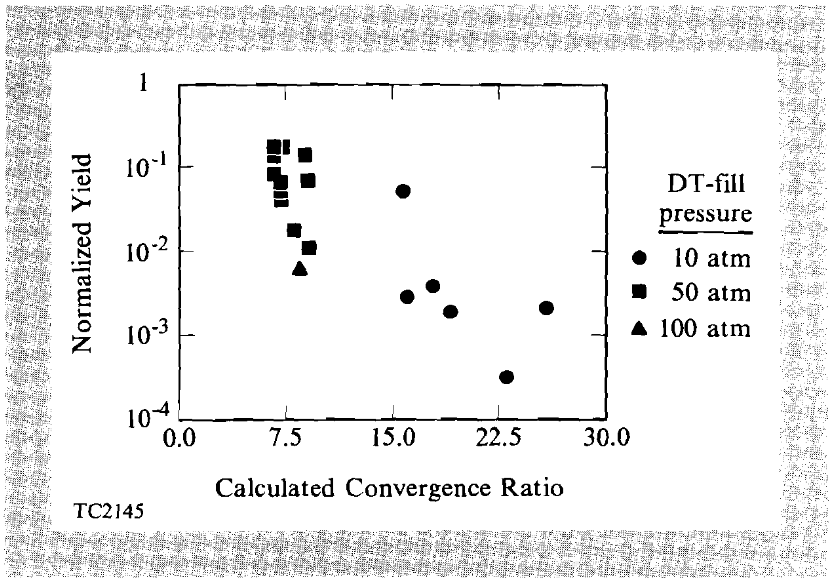

Fig. 31.2
Dependence of the ratio of the measured-to-predicted neutron yield as a function of the calculated convergence ratio.

neutron yield is severely degraded. A similar, in fact steeper, dependence was observed in earlier experiments with large-aspect-ratio targets.[16] This feature is most probably dependent on the illumination uniformity. The improved level of uniformity in the latest results lessens the falloff toward higher convergence ratios.

The most reliable scaling data from which the compressed core density can be inferred was collected from neutron activation of silicon in the glass. The details of this diagnostic system on OMEGA have been described previously.[6] However, for the present series of experiments a modification was made to the target debris collection system used to capture a fraction of the imploded shell, which has been activated by the neutron burst. In all previous experiments,[17] the debris collection cone had an efficiency of ~1%, limited by beam geometrical considerations. However, for the present experiments, this cone collector was augmented with a plasma blowoff shroud, produced off the inside of a metal enclosure, through which the beams are focused onto the target (Fig. 31.3). For these glass shell targets, the overall collection efficiency was measured to be 25%. This efficiency level permitted the measurement of Y_n $<\rho\Delta R>$ values as low as 4×10^5. The variation of shell $\rho\Delta R$ as a function of calculated convergence ratio is shown in Fig. 31.4(a). Both experimental data and 1-D code predictions are shown. As expected, the compressed shell $\rho\Delta R$ increases with the calculated convergence ratio. The experimental data follows the code predictions quite well, at least to convergence ratios of ~20. Above this value, there is a falloff in the experimental data. This falloff can also be seen by comparing the measured to the predicted value of $\rho\Delta R$ [Fig. 31.4(b)]. Similar data for low-Z ablator targets is shown in Figs. 31.4(c) and 31.4(d). The degradation in target performance is even more marked in this case.

From a knowledge of the measured shell $\rho\Delta R$, and with the assumptions of implosion symmetry, isotropic fuel density, and negligible fuel-shell mixing, it is possible to estimate the fuel density at peak neutron yield.[18] With these assumptions it is easy to show that

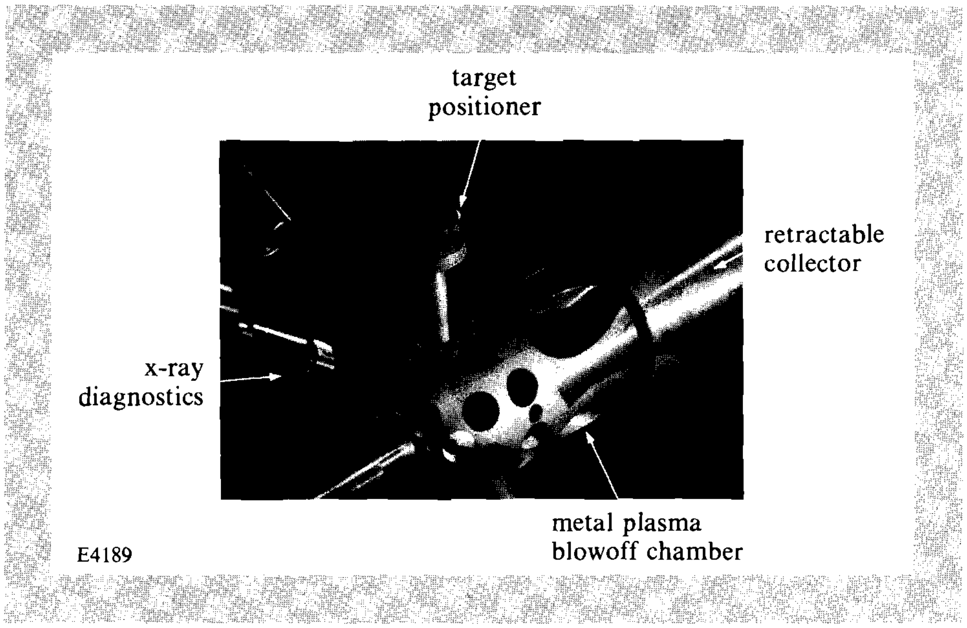

Fig. 31.3
Photograph of the plasma shroud enclosure used to boost the debris-collection efficiency.

$$\left(\frac{\rho_f}{\rho_{fo}}\right)^{2/3} = \frac{\rho \Delta R}{\rho_o \Delta R_o}\left[1+\frac{\Delta R}{R_f}+\frac{1}{3}\left(\frac{\Delta R}{R_f}\right)^2\right] \Big/ \left[1+\frac{\Delta R_o}{R_{fo}}+\frac{1}{3}\left(\frac{\Delta R_o}{R_{fo}}\right)^2\right], \quad (1)$$

where ρ_f and R_f are the fuel density and radius, ρ and ΔR are the pusher density and radius, and the suffix o represents the original, unimploded value. For the thick-walled targets considered here, it can be shown that a target having fuel mass M_f and pusher mass M_p, the compressed fuel density can be expressed as

$$\rho_f = \left\{2\left(\frac{3M_f}{4\pi}\right)^{\frac{1}{3}}\left[\left(1+\frac{M_p}{2M_f}\right)^{\frac{1}{3}}-1\right]\right\}^{-\frac{3}{2}} (\rho \Delta R)^{\frac{3}{2}} . \quad (2)$$

For the data shown in Fig. 31.4, the corresponding densities are shown in Fig. 31.5. The estimated fuel density can exceed 50 XLD (10 g/cc) for both glass shell and low-Z ablator targets.

In summary, these experiments have demonstrated the achievement of high compressed fuel densities – in excess of 50 XLD, in targets irradiated by the 351-nm OMEGA laser system – for exceedingly modest incident laser energies (< 1.5 kJ). These implosions, to first order, agree well with the predictions of *LILAC*, at least for expected convergence ratios of <20. The influence of nonuniformities in the irradiation distribution is assessed from the degradation in the neutron yield with the convergence ratio. The impact of hot spots in the beam distribution on low-Z ablator targets is evidenced by early x-ray lightup times in the shell and by lower than predicted yields. This phenomena in CH targets is under further study, since most high-gain ignition demonstration targets are fabricated of polymer materials. Nonetheless, the close agreement of the measured and predicted shell areal densities for both glass and low-Z ablator targets is encouraging and augurs well for our upcoming cryogenic target implosions, which should produce much higher compressed fuel densities. Progressive

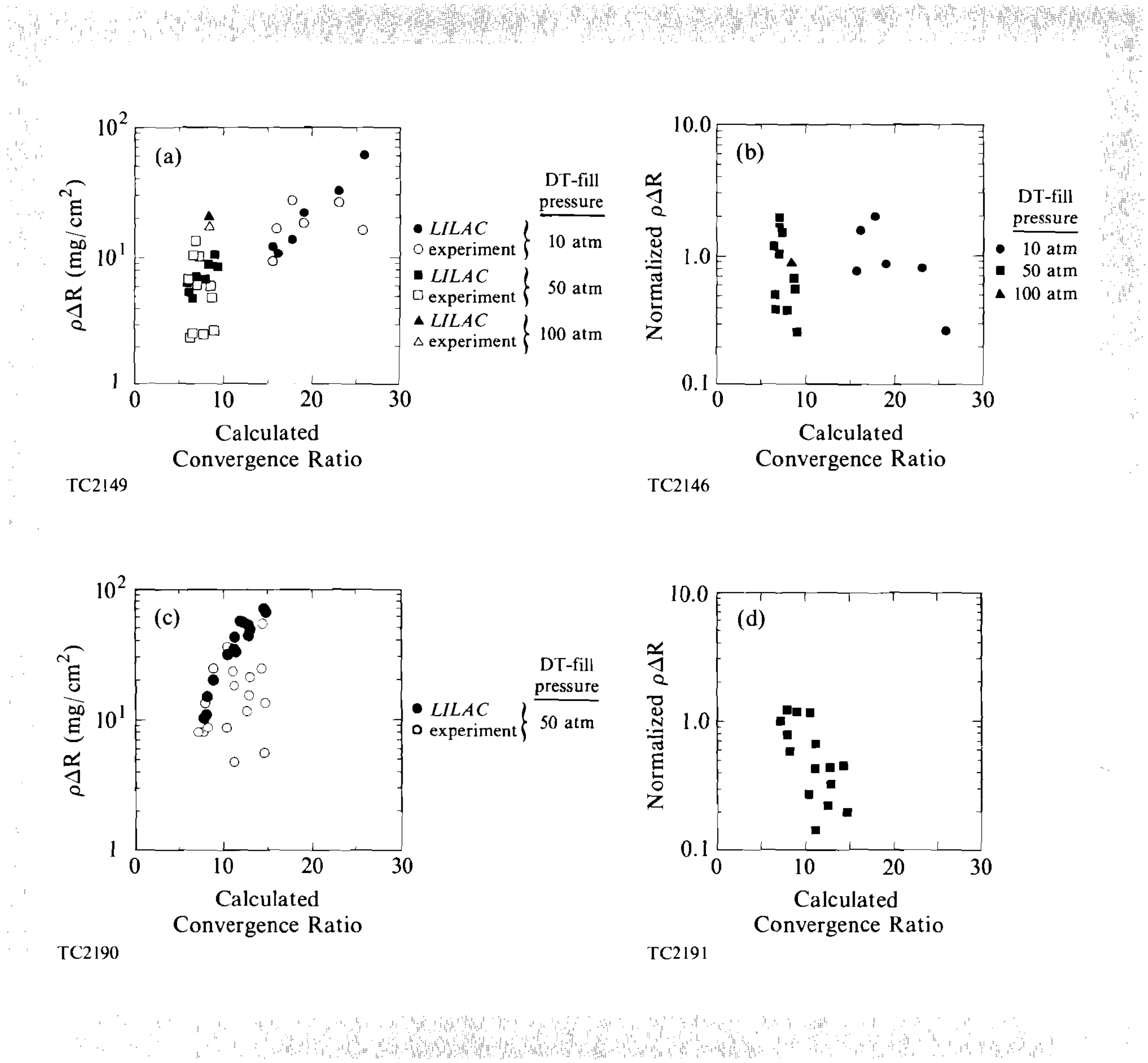

Fig. 31.4
Summary of shell areal density data acquired on glass shell targets (a) and (b) and on low-*Z* plastic ablator targets (c) and (d).

improvement of the illumination uniformity, and elimination of the effects of hot spots in the intensity distribution, should permit the symmetric implosion of targets having convergence ratios as high as those required for ignition scaling experiments.

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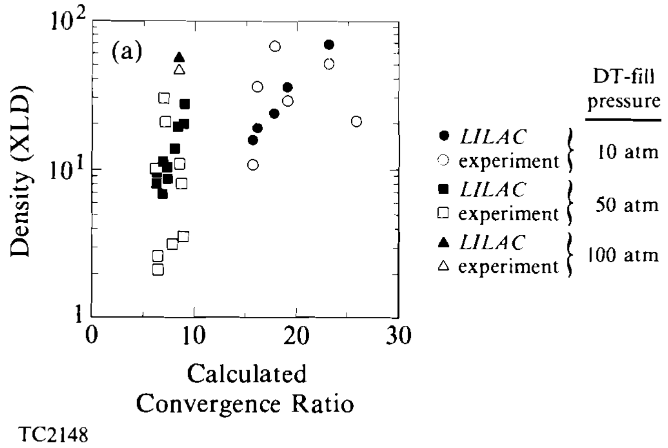

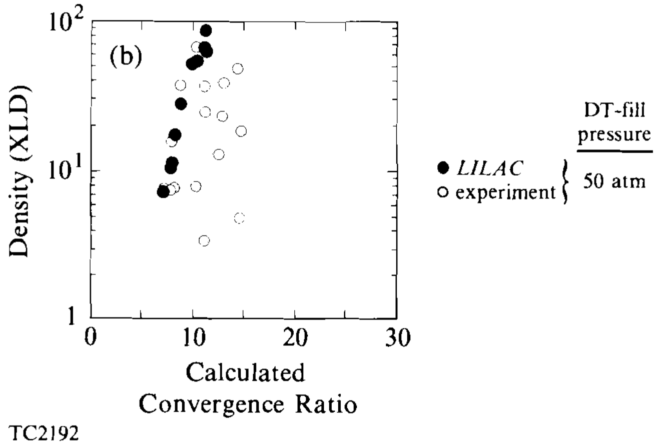

Fig. 31.5
Estimated fuel densities for glass shell and low-*Z* ablator targets.

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