Executive Summary

The fiscal year ending September 2000 (FY00) concluded the third year of the cooperative agreement (DE-FC03-92SF19460) five-year renewal with the U. S. Department of Energy (DOE). This report summarizes research at the Laboratory for Laser Energetics (LLE), the operation of the National Laser Users' Facility (NLUF), and programs involving education of high school, undergraduate, and graduate students during the year.

Progress in Laser Fusion

A major goal of the Laboratory for Laser Energetics is to develop the direct-drive approach to inertial fusion for an ignition and gain demonstration on the National Ignition Facility (NIF) currently under construction at the Lawrence Livermore National Laboratory (LLNL). This challenging goal requires precision laser diagnostics and controls, a cryogenic target handling system, sophisticated experimental diagnostics, robust theoretical and computational modeling, and the development of new laser and optical technologies.

At LLE the stability of direct-drive NIF capsules has been studied, and the conditions under which direct-drive NIF capsules ignite are being examined. A numerical study (pp. 1–5) uses two-dimensional hydrodynamic simulations in conjunction with a model that includes the various mechanisms that can influence target performance. Laser nonuniformities and the inner-surface roughness of the DT ice in direct-drive cryogenic capsules have been identified as the principal seeds of the instabilities that can potentially quench ignition. We believe that a target gain greater than 10 can be achieved for a realistic inner-surface ice roughness when beam smoothing with 2-D smoothing by spectral dispersion (SSD) and a bandwidth greater than 0.5 THz is used. Another set of two-dimensional calculations (pp. 181–190) demonstrates how various contributors to implosion disruption (laser imprinting, power imbalance, and target roughness) affect target performance and final gain for NIF target designs.

Two-dimensional hydrodynamic simulations in conjunction with a stability analysis model to study the performance of OMEGA cryogenic capsules show that these targets are energy scaled from the NIF ignition designs and have similar 1-D behavior and stability properties. This similarity will facilitate the extrapolation of cryogenic target studies on OMEGA to ignition targets on the NIF.

A novel technique for laser-imprint reduction in OMEGA cryogenic capsules (pp. 56–62) shows considerable promise. Laser nonuniformities can imprint a target with a "seed" that can cause debilitating hydrodynamic instabilities. Using the two-dimensional hydrodynamics code *ORCHID*, investigations show that an initial spike in the laser pulse can reduce laser imprint by about a factor of 2 for typical target configurations and especially for the nonuniformity modes considered most dangerous for target performance. Further, this modification to the laser pulse need not significantly degrade target performance and is accompanied by only a modest decrease in the one-dimensional neutron yield.

A judicious choice of materials and target dimensions allows one to infer the amount of fast-electron preheat due to laser irradiation on OMEGA. Significant fast-electron preheat can substantially decrease the effectiveness of a direct-drive implosion. Beginning on p. 63, we report on an experiment in planar geometry. The results from this measurement will be used as a reference point to determine fast-electron preheat in ignition-relevant direct-drive spherical targets.

Experimental measurements of target irradiation nonuniformity in the absence of SSD have indicated lower-than-expected levels of nonuniformity. Shots without SSD are baseline measurements for OMEGA; consequently, modeling these shots provides a more complete understanding of the target irradiation nonuniformity. Beginning on p. 78, we report on comparisons of numerical simulations of laser smoothing with measurements. The intensity-dependent phase accumulations by the OMEGA laser (*B*-integral) is identified as the mechanism for the observed smoothing. We found that we can successfully model these *B*-integral-related smoothing mechanisms and find them to be relatively minor compared to the dominant smoothing effect of SSD.

Measurements (pp. 173–180) of the effect of beam smoothing and pulse shape on imprinting show reduced levels of imprint with the higher beam smoothing afforded by 1-THz SSD.

An investigation of the laser prepulse levels on OMEGA (pp. 30–36) has helped to establish a contrast criterion for direct-drive implosions. Control of laser prepulses can be critical since high-intensity prepulses can potentially compromise the aluminum layer and cause unwanted laser damage to direct-drive targets. While OMEGA intermittently produces measurable prepulses, the prepulse level is not expected to significantly degrade target performance.

We report on the results of a series of direct-drive implosions of gas-fusion-fuel–filled plastic shells performed on the OMEGA laser system. The experiments include those performed with 1-THz SSD and high-quality power balance (pp. 191–198).

OMEGA time-integrated x-ray diagnostics have been converted to electronic readout using direct-detection x-ray cameras [charge-injection devices (CID's)]. Pinhole and x-ray microscope images are shown along with inferred calibration measurements of the CID cameras (pp. 119–123). Currently, the same cameras are being used to obtain x-ray spectra in a TIM-based spectrometer, extending their use to all time-integrated imaging and spectroscopic x-ray instruments used on OMEGA.

The spatial structure of the temperature and density of target-shell plasmas at peak compression (stagnation) has been investigated experimentally (pp. 124–129). This is accomplished by examining the energy dependence of the x-ray emission using narrow-band x-ray filters and the known absorption properties of the shell dopant (Ti). A technique to measure the positional dependence of x-ray self-absorption with filtered x-ray framing cameras (pp. 204–213) shows how compressed shell nonuniformities can be measured by carefully modeling the imaging system.

The physics and instrumentation used to obtain and interpret secondary D-^{3}He proton spectra from current gas-filled-target experiments and future cryogenic-target experiments (pp. 130–141) is presented in some detail. Through a novel extension of existing charged-particle detection techniques with track detectors, we now have the ability to obtain secondary proton spectra with increased sensitivity. We have also found that we can measure the secondary neutron yield (DT neutron yield from D_2-filled targets) using current-mode detectors (pp. 199–203). The current-mode detectors can be configured to survey a much larger dynamic range than single-event neutron counters.

Collaborative experiments on OMEGA have continued between LLE and Los Alamos National Laboratory (LANL) on indirect-drive capsule implosions in tetrahedral hohlraums. These hohlraums are particularly well suited to the OMEGA target chamber geometry and have been shown to provide an extremely uniform radiation drive. A principal tool used in this investigation is a three-dimensional (3-D) view-factor code including a time-dependent radiation-transport model in the hohlraum wall and a perturbation treatment of a near-spherically symmetric hydrodynamic implosion of the capsule (pp. 90–106). Simulations of x-ray images of the imploded core with a 3-D x-ray postprocessor show close agreement with experiment on several quantities including radiation drive temperatures, fusion yields, and core deformation.

Cryogenic Target Technology

This year we measured the initial performance of the high-pressure deuterium- and tritium-filling portion of the Cryogenic Target Handling System (pp. 6–11). Thick-walled plastic targets have been successfully pressurized with deuterium to the required levels by this high-pressure filling system. Adequate control of the various factors influencing the filling process has been demonstrated, indicating that even thin-walled plastic targets (such as those required by the cryogenic target designs for OMEGA) can be successfully filled to the required high pressure.

The target detection and shroud pull-sequencing aspects of cryogenic target operations on OMEGA are detailed beginning on p. 21. The newly designed Cryogenic Target Detection System is based on existing elements of OMEGA controls and provides the necessary sequencing, safety features, and flexibility to allow for the evolution of cryogenic target operations.

A numerical study of the principal sources of target nonuniformities for a cryogenic target when placed in the layering sphere is summarized beginning on p. 12. Deviations from idealized symmetry in the capsule-wall thickness, the displacement of the capsule relative to the center of the layering sphere, and the existence of temperature gradients on the layering sphere's inner surface can result in temperature gradients across the cryogenic target. This in turn affects the uniformity of the cryogenic fuel layer. Calculations of the temperature profile in these targets will be used to guide target fabrication and layering.

Lasers and Optical Materials Technology

Dyes for a liquid crystal–based interferometer to be used on OMEGA for more-accurate wavefront characterization (pp. 37–47) have been identified. Using state-of-the-art computational chemistry tools we have demonstrated the effectiveness of modeling in guiding experimental searches for new dye compounds. The work also has potential for other liquid crystal devices used in optical communications and sensor protection. In other work on interferometry, we have compared the utility of a novel liquid crystal–based, point-diffraction interferometer (LCPDI) with the commercial standard phase-shifting interferometer and conclude that the LCPDI is a viable low-cost alternative (pp. 142–156).

Ongoing experimental and theoretical work relating to holographic grating design and fabrication has resulted in high-diffraction-efficiency, high-wavefront-quality gratings used on the OMEGA laser primarily for laser-beam smoothing and spectroscopy (pp. 71–77). For the high-optical-quality gratings required on OMEGA, it is critical to control environmental factors including humidity, thermal gradients, and air turbulence during grating fabrication. Future work will involve improved modeling of these gratings and further experimental investigations.

Knowledge of the hardness of abrasive particles is a key to understanding the mechanisms of material removal in polishing optical glass. Measurements of the nanohardness of magnetic and nonmagnetic particles used in the magnetorheological finishing (MRF) process are discussed beginning on p. 107. The nanoindentation technique allows for the characterization of mechanical properties of small abrasive particles, which is not possible through traditional microhardness measurement methods. With abrasive particle characterization now possible, subsequent experiments with different combinations of abrasive particles can provide information regarding removal mechanisms in MRF. Additional details about the mechanisms of glass polishing using the MRF technique currently being studied in the Center for Optics Manufacturing (COM) begin on p. 157. Material-removal experiments show that the nanohardness of carbonyl iron (CI) is important in MRF with nonaqueous MR fluids with no nonmagnetic abrasives, but is relatively unimportant in aqueous MR fluids and/or when nonmagnetic abrasives are present.

Laser Facility Report

OMEGA operations during FY00 (p. 216) yielded a total of 1153 target shots, including 284 shots for LLNL, 131 for LANL, 11 for Sandia National Laboratory (SNL), 11 for the French Commissariat à l'Énergie Atomique (CEA), and 124 for the National Laser Users' Facility (NLUF). The principal achievements include activation and testing of the full suite of cryogenic target handling system equipment, improvements to the single-beam uniformity using 1-THz SSD, and significant improvements in the beam-to-beam power fluctuations. This progress required the installation of 60 distributed polarization rotators, a modification to the harmonic conversion cells to accommodate increased bandwidth, and improvements to the SSD equipment.

National Laser Users' Facility

During FY00, external use of OMEGA increased by 12% over the prior fiscal year, accounting for 50% of the total target shots. The seven NLUF experimental campaigns are summarized beginning on p. 217. Shots conducted during the year for the National Laboratories, nuclear weapons effects testing, and the CEA programs are summarized beginning on p. 222. LLNL usage included measurements of x-ray conversion efficiency, experiments on "cocktail" hohlraums, NIF laser beam "foot" symmetry measurements, high-convergence implosions, shock timing, ablator burnthrough, convergent ablator burnthrough, planar Rayleigh–Taylor experiments, experiments on pushered shells, hydrodynamic experiments, and other radiation drive experiments. The LANL campaigns examined the behavior of double-shell targets, direct-drive cylindrical experiments, backlighter studies, high-convergence implosions, Rayleigh–Taylor instability studies, and high-yield shots for neutron diagnostics. LANL also supported additional campaigns at OMEGA: SNL WBS3 ablator characterization, NLUF laser–plasma instability research, jet experiments in collaboration with the United Kingdom's Atomic Weapons Establishment, and transient x-ray diffraction materials work. The French CEA activities included time-resolved broadband x-ray spectroscopic studies, x-ray conversion experiments, and neutron imaging of an imploding DT target.

Education at LLE

As the only major university participant in the National ICF Program, education continues to be an important mission for the Laboratory. Graduate students are using the world's most powerful ultraviolet laser for fusion research on OMEGA, making significant contributions to LLE's research activities. Fourteen faculty from five departments collaborate with LLE's scientists and engineers. Presently 55 graduate students are pursuing Ph.D. degrees at the Laboratory. The research includes theoretical and experimental plasma physics, high-energy-density plasma physics, x-ray and atomic physics, nuclear fusion, ultrafast optoelectronics, high-power-laser development and applications, nonlinear optics, optical materials and optical fabrications technology, and target fabrication. Technological developments from ongoing Ph.D. research will continue to play an important role on OMEGA.

One hundred forty-one University of Rochester students have earned Ph.D. degrees at LLE since its founding. An additional 70 graduate students and 21 postdoctoral positions from other universities were funded by NLUF grants. The most recent University of Rochester Ph.D. graduates and their thesis titles are

Brian J. Buerke	*Accurate Measurement of Tunneling Ionization Rates of Atoms in a High-Intensity Laser Field*
Jan L. Chaloupka	*Observation of Electron Trapping in an Intense Laser Beam*
Selena Chan	*Porous Silicon Multilayer Structures: From Interference Filters to Light-Emitting Devices to Biosensors*
Faiz Dahmani	*Laser-Driven Mechanical Fracture in Fused Silica*
Andres C. Gaeris	*The Stimulated Brillouin Scattering During the Interaction of Picosecond Laser Pulses with Moderate-Scale-Length Plasmas*
Kenton A. Green	*Characterization of Time- and Frequency-Varying Optoelectronic Microwave Silicon Switches*
Karl D. Hirschman	*Fabrication, Characterization, and Integration of Oxide Passivated Nano-crystalline Silicon Light-Emitting Devices*
Oleg A. Konoplev	*Generation and Measurement of High-Contrast, Ultrashort Intense Laser Pulses*
John M. Larkin	*Optical and Photodynamic Properties of the Higher-Lying States of Rose Bengal*
Stuart J. McNaught	*Precise Measurements of Electron Initial Conditions for Tunneling Ionization in an Intense, Elliptically Polarized Laser Field*
Han Pu	*Properties of Multiple-Component Bose-Einstein Condensate*
James P. Shaffer	*Heteronuclear and Homonuclear Ultracold Optical Collisions Involving Na and Cs: Parts I and II*
Aric B. Shorey	*Mechanisms of Material Removal in Magnetorheological Finishing (MRF) of Glass*
Leon J. Waxer	*Quantum State Measurement for Molecules*

Approximately 55 University of Rochester undergraduate students participated in work or research projects at LLE this past year. Student projects include operational maintenance of the OMEGA laser system, work in the materials and optical-thin-film coating laboratories, programming, image processing, and diagnostic development. This is a unique opportunity for students, many of whom will go on to pursue a higher degree in the area in which they gained experience at the Laboratory.

LLE continues to run a Summer High School Student Research Program (pp. 214–215), where this year 13 high school juniors spent eight weeks performing individual research projects. Each student is individually supervised by a staff scientist or an engineer. At the conclusion of the program, the students make final oral and written presentations on their work. The reports are published as an LLE report.

In 2000, LLE presented its fourth William D. Ryan Inspirational Teacher Award to Mr. James Shannon of Pittsford–Mendon High School. Alumni of our Summer High School Student Research Program were asked to nominate teachers who had a major role in sparking their interest in science, mathematics, and/or technology. This award, which includes a $1000 cash prize, was presented at the High School Student Summer Research Symposium. Mr. Shannon, a chemistry teacher, was nominated by three alumni of the Research Program: Mr. Chen-Lin Lee (1994 participant), Mr. Steven Costello (1998 participant), and Ms. Leslie Lai (1998 participant).

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