Executive Summary

The fiscal year ending September 2004 concluded the second year of the second five-year renewal of the cooperative agreement DE-FC03-92SF19460 with the U.S. Department of Energy (DOE). This report summarizes research at the Laboratory for Laser Energetics (LLE) conducted during the year, operation of the National Laser Users' Facility (NLUF), a status report of the new OMEGA Extended Performance (EP) laser project, and programs concerning the education of high school, undergraduate, and graduate students during the year.

Progress in Laser Fusion Research

1. OMEGA Direct-Drive Experiments

Layered and characterized cryogenic D_2 capsules have been imploded using high-contrast pulse shapes on the 60-beam OMEGA laser at the Laboratory for Laser Energetics. These experiments (p. 1) measure the sensitivity of the direct-drive implosion performance to parameters such as the inner-ice-surface roughness, the adiabat of the fuel during the implosion, and the laser power balance. The goal is to demonstrate a high neutron-averaged fuel ρR with low angular variance using a scaled $\alpha \sim 3$ ignition pulse shape driving a scaled all-DT ignition capsule. Results are reported with improvements over previous experiments in target layering and characterization and in laser pointing and target positioning on the OMEGA laser. These capsules have been imploded using up to 23 kJ of 351-nm laser light with an on-target energy imbalance of less than 2% rms, full beam smoothing (1-THz bandwidth, 2-D SSD, and polarization smoothing), and new, optimized, distributed phase plates. Pulse shapes include high-adiabat ($\alpha \sim$ 25) square pulses and low-adiabat ($\alpha < 5$) shaped pulses. The data from neutron and charged-particle diagnostics, as well as static and time-resolved x-ray images of the imploding core, are compared with 1-D and 2-D numerical simulations. Scaling of target performance to a weighted quadrature of inner ice roughness at the end of the acceleration phase is investigated.

We have characterized the compressed-core, temperature-density profiles of a cryogenic deuterium (D_2) target using measured primary deuterium–deuterium (DD) and secondary deuterium–tritium (DT) yields, neutron-averaged ion temperature, and x-ray images at peak neutron production, and to infer the electron pressure and the areal density of the neutron production region to be 2.7±0.4 Gbar and ~10 mg/cm^2, respectively.

"Performance of 1-THz-Bandwidth, 2-D Smoothing by Spectral Dispersion and Polarization Smoothing of High-Power, Solid-State Laser Beams" (p. 49) discusses the laser-beam smoothing achieved with 1-THz-bandwidth, two-dimensional smoothing by spectral dispersion and polarization smoothing on the 60-beam, 30-kJ, 351-nm OMEGA laser system. These beam-smoothing techniques are directly applicable to direct-drive ignition target designs for the 192-beam, 1.8-MJ, 351-nm National Ignition Facility. Equivalent-target-plane images for constant-intensity laser pulses of varying duration were used to determine the smoothing. The properties of the phase plates, frequency modulators, and birefringent wedges were simulated and found to be in good agreement with the measurements.

The target areal-density (ρR) asymmetries in OMEGA direct-drive spherical implosions can be inferred experimentally. The rms variation for a low-mode-number structure is approximately proportional to the rms variation of on-target laser intensity with an amplification factor of ~1/2(C_r–1), where C_r is the capsule convergence ratio. This result has critical implications for future work on the National Ignition Facility (NIF) as well as on OMEGA (see p. 67). In related work (p. 122) we investigate models for determining the areal density of hot fuel (ρR_{hot}) in compressed, D_2-filled capsules. Measurements from three classes of direct-drive implosions on OMEGA were combined with Monte Carlo simulations to assess the impact of mix and other factors on the determination of ρR_{hot}. The results of the Monte Carlo calculations were compared to predictions of simple commonly used models that use ratios of either secondary D^3He proton yields or secondary DT neutron yields to primary DD neutron yields to provide estimates of $\rho R_{\mathrm{hot},p}$ or $\rho R_{\mathrm{hot},n}$, respectively, for ρR_{hot}.

Measurements of the imprint efficiency in 20-μm-thick plastic foils driven by 351-nm laser light at an intensity ~2×10^{14} W/cm^2 are described beginning on p. 90. The measured target spatial modulations were imprinted from spatial laser nonuniformities during laser-ablated plasma formation at the beginning of the drive. The laser modulations consisted of broadband nonuniformities from six beams incident at 23° to the target normal and single-mode perturbations from one beam incident at 48° to the target normal. The measurements were performed at a spatial wavelength of 60 μm with and without smoothing by spectral dispersion (SSD). The measured imprint efficiencies at 60-μm spatial wavelength were 2.5±0.2 μm for the beam with 48° angle of incidence and 3.0±0.3 μm for the beams with 23° angle of incidence. The SSD reduced modulations by a factor of ~2.5 at the same spatial wavelength.

The article "Multidimensional Simulations of Plastic-Shell Implosions on the OMEGA Laser" (p. 139) describes the application of the multidimensional hydrodynamic code *DRACO* to study shell stability during the acceleration phase in the presence of nonuniform illumination and target roughness. Simulations show that for thick shells remaining integral during the acceleration, the target yield is reduced by a combination of long-wavelength modes due to surface roughness and beam-to-beam imbalance and intermediate modes due to single-beam nonuniformities. Compared to 1-D predictions, the neutron-production rate for these shells truncates. Diminished yield for thin shells is mainly due to shell breakup at short-wavelength scales of the order of the in-flight shell thickness. *DRACO* simulation results are consistent with experimental observations.

2. Diagnostic Techniques

We report on shielding strategies to optimize the signal-to-background ratio and to obtain high-quality x-ray spectra (p. 103). The use of a single-photon–counting x-ray CCD camera as an x-ray spectrometer is a well-established technique in ultra-short-pulse laser experiments. In the single-photon–counting mode, the pixel value of each readout pixel is proportional to the energy deposited from the incident x-ray photon. For photons below 100 keV, a significant fraction of the events deposits all energy in a single pixel. A histogram of the pixel readout values gives a good approximation of the x-ray spectrum. This technique requires almost no alignment, but it is very sensitive to signal-to-background issues, especially in a high-energy petawatt environment.

A comprehensive overview of the methodology and issues involved in the preparation of deuterium-ice layers in OMEGA targets is given beginning on p. 160. The process of first forming and then smoothing the ice layer is governed by multiple parameters that, when optimally controlled, yield ice layers approaching a 1-μm-rms roughness in low-spatial-frequency modes.

During the year, we have developed and fielded a new, modular x-ray streaked imager that combines a four-mirror Kirkpatrick–Baez microscope with a high-current PJX streak tube (p. 183). The streak tube has been designed for optimum performance at 1.5 keV with better-than-5 μm spatial resolution over its central 200-μm field of view.

LLE scientists discuss several prototypes of NIF neutron-time-of-flight detectors developed and tested on OMEGA (p. 202). Based on OMEGA results, these detectors will be able to measure ion temperatures of, and neutron yields from, NIF targets generating between 10^9 and 10^{19} neutrons.

A new method for accurately measuring beam position, shape, and relative intensity of the OMEGA system's 60 beams from CID-recorded, focal-spot x-ray images from 4-mm, Au-coated pointing targets is discussed beginning on p. 252. This method provides pivotal input into efforts to improve target-illumination uniformity by improving beam pointing and reducing variations in beam intensities from average.

3. Theory and Simulation

A brief study was completed on the contribution of the gradients in the laser-induced electric field to the current flow, heat flux, and electric stress tensor in laser-produced plasmas (p. 54). The transport coefficients, previously derived in the limit $Z >> 1$, are obtained for an arbitrary ion charge Z. It is shown that the ponderomotive terms significantly modify the thermal transport near the laser turning points and the critical surface.

The ion-fluid and Poisson (IFP) equations with phenomenological damping terms and the light-wave equation are used to describe stimulated Brillouin scattering (SBS) in one- and two-ion plasmas (p. 73). Comparing numerical and analytical results in the linear limit tested the computer code. The code is used to compare effects of Landau damping, pump depletion, and ion-acoustic nonlinearities on the saturation of SBS in one- and two-ion plasmas. In the latter, SBS from fast and slow ion-acoustic waves is considered separately. SBS is simulated for hydrocarbon (CH) plasmas with parameters typical for experiments on OMEGA.

LLE scientists collaborating with scientists from the Massachusetts Institute of Technology developed an analytical model of the interaction of directed energetic electrons with a high-temperature hydrogenic plasma (p. 97). The randomizing effect of scattering off both plasma ions and electrons is treated from a unified point of view. For electron energies of less than 3 MeV, electron scattering is equally important. The net effect of multiple scattering is to reduce the penetration from 0.54 to 0.41 g/cm^2 for 1-MeV electrons in a 300-g/cm^3 plasma at 5 keV. These considerations are relevant to "fast ignition" and to fuel preheat for inertial confinement fusion.

The theory of the adiabat profile induced by a strong shock propagating through a relaxed density profile in inertial confinement fusion (ICF) capsules is described in the article beginning on p. 106. The relaxed profile is produced through a laser prepulse, while the foot of the main laser pulse drives the adiabat-shaping shock. The adiabat shape is calculated for the cases of intense, short prepulses and weak, long prepulses. The theoretical adiabat profiles accurately reproduce the simulation results to within a few-percent error. ICF capsules with a shaped adiabat are expected to benefit from improved hydrodynamic stability while maintaining the same one-dimensional performances as constant-adiabat shells.

Wetted foams are of great interest in improving the gain by increasing the absorption in ignition-scale targets. Aspects of the hydrodynamic behavior of foams are discussed in the article "Shock Propagation in Deuterium–Tritium–Saturated Foam" (p. 227). Testing the assumption of homogeneous mixing in fibrous foams saturated with cryogenic deuterium and tritium, shock passage in wetted-foam mixtures was simulated by the adaptive-mesh, two-dimensional hydrodynamic code *AstroBEAR*. For foam fibers of ~1/10-μm diameter and relevant foam densities, the mixing length behind the shock is found to be of the order of microns. Transverse motion dampens out sufficiently that, at the mixing region's edge farthest from the shock, Rankine–Hugoniot jump conditions are obeyed to within a few percent and shock speeds are also within a few percent of their homogeneous values. In addition, questions of feedthrough and feedout are addressed, showing that the stability of the shock front, once it leaves the wetted-foam layer, minimizes the effect of feedthrough. As a result, simulations of whole-foam-pellet implosions may model the wetted foam as a homogeneous mixture.

4. High-Energy-Density Physics

Scientists at LLE and a number of institutions have collaborated on an experiment that uses a laser-source–based, extended x-ray absorption fine structure (EXAFS) measurement to study the properties of laser-shocked metals on a nanosecond time scale (p. 16). The ability to measure shock-induced temperatures of the order of 0.1 eV is essentially unique to EXAFS. EXAFS measurements of vanadium shocked to ~0.5 Mbar with a 3-ns laser pulse yield a compression and temperature in good agreement with hydrodynamic simulations and shock-speed measurements. In laser-shocked titanium at the same pressure, the EXAFS modulation damping is much higher than warranted by the increase in temperature. This is explained by the α-Ti to ω-Ti phase transformation known to occur around ~0.1 Mbar in the longer (μs) shocks obtained in gas-gun experiments. In the ω-Ti phase, the disparate neighbor distances cause a beating of the modulation frequencies and thus an increased damping. These results demonstrate that EXAFS measurements can be used for the study of nanosecond-scale shocks and phase transformations in metals.

Lasers, Optical Materials, and Advanced Technology

An ytterbium fiber laser mode-locked at its 280th harmonic, which corresponds to a repetition rate greater than 10 GHz, has been demonstrated (p. 36). The laser produces linearly polarized, 2.6-ps chirped pulses with up to 38 mW of average output power. The mode-locked pulses are tunable over a 55-nm window centered on 1053 nm.

We have conducted a series of microgrinding and polishing experiments on glass-ceramics (p. 40). Microgrinding includes deterministic microgrinding (fixed infeed rate) and loose-abrasive lapping (fixed pressure). Material mechanical properties (Young's modulus, hardness, fracture toughness) and chemical properties (chemical susceptibility, or mass loss under chemical attack) are correlated with the quality of the resulting surface (surface microroughness and surface grinding–induced residual stresses). Deterministic microgrinding (at fixed infeed) and loose-abrasive microgrinding (at fixed pressure) are compared in terms of material removal rates and resulting surface quality.

We have demonstrated a technique to improve laser power-amplifier performance through compensating laser-rod bulk inhomogeneities by magnetorheological single-surface wavefront correction (p. 194). Large-aperture rods corrected in this manner render nearly diffraction limited output-beam performance.

The chemical durability of water-sensitive phosphate laser glass to different polishing and cleaning conditions has been examined (p. 257). We find the absence of an unambiguous correlation between initial finished surface quality of any glass type tested and quantifiable magnitude of humidity-driven degradation, whereas subsequent aqueous cleaning does increase haze: more so for pitch and pad–finished surfaces than for MRF-processed ones.

We provide an update on the OMEGA EP tiled-grating-compressor technology (p. 242). For the first time, real-time, computer-controlled phasing of a grating triplet, using interferometric feedback via nanopositioners, has been demonstrated and a transform-limited far-field spot achieved.

We have tested metal–semiconductor–metal ultraviolet photodiodes fabricated on GaN in the picosecond regime with an electro-optic sampling system (p. 25). The best performance of a device with a feature size of 1 μm showed a 1.4-ps rise time and 3.5-ps full width at half maximum, which represents the fastest ultraviolet GaN photodiode reported to date. The derived electron velocity in GaN was in good agreement with an independent photoexcitation measurement. A comparison with Monte Carlo simulation was made, and slower impulse response observed in a device with a smaller feature size of 0.5 μm was discussed. In related work we introduce a submicron-scale ultraviolet photodiode based on a metal–semiconductor–metal structure on GaN (p. 212). The authors built, tested, and then simulated the circuit by a distributed-circuit approach that yielded close agreement between theory and observation of the impulse-response, space-charge-screening broadening found in the device.

Photonic crystals offer great promise in a variety of applications in optoelectronics, from lasers to the creation of all-optical circuits for computing (p. 25). The research project focused on the creation of novel photonic crystals through the self-assembly of core-shell structured colloidal particles. Layer-by-layer electrostatic self-assembly was used to deposit polyelectrolyte shells around spherical colloidal particles. By exploiting electrostatic attraction, shells of controllable thickness were formed by alternating the deposition of positive- and negative-charged polyelectrolytes. The coated colloidal particles were deposited as thin films of hexagonally close-packed crystals onto glass slides. The crystalline films display a partial photonic band gap and preferentially reflect light of a wavelength dependent on the size of the particles making up the crystal. The chemical functional groups in the shell surrounding the colloidal particles offer a potential route to immobilize optically active species in the shell to enhance the photonic band gap of the crystal.

Ultrafast current sensing has reached a new level of sensitivity and speed by taking advantage of the magneto-optic Faraday effect in CdMnTe single crystals (p. 208). To date, response times of a few hundred femtoseconds can be realized at a current sensitivity of ~0.1 mA at 10 K.

A new method for patterning nanoparticles and self-assembled monolayers through the use of elastomeric stamps and their controlled deformation by overpressure has been developed (p. 218). The method enables pattern formation on a scale length up to an order of magnitude smaller than the original stamps as well as patterns that do not exist in the original masters. As one example, magnetic ring and anti-ring structures are being fabricated for memory-device applications.

Single-walled carbon nanotubes have been analyzed at a spatial resolution of 10 to 20 nm by employing near-field Raman imaging and spectroscopy (p. 269). For individual, isolated carbon nanotubes, they find a nonuniform distribution of Raman bands along the tube axis.

An ac-stabilizing field has been used to control the orientation and motion of polymer cholesteric-liquid-crystal flakes suspended in a host fluid (p. 274). With a display application in mind, the authors show that the field acts on an induced dipole moment on the flake surface due to interfacial Maxwell–Wagner polarization.

Status and Progress on OMEGA EP

The OMEGA EP (Extended Performance) project completed the majority of the preliminary design phase and moved into the project execution phase during FY04. Starting in FY03 with $13 million in funding, the project continued with $20 million in FY04 funding. Concomitantly, NNSA project authorizations in FY04 included the approval of the Performance Baseline (Critical Decision 2) and approval to Start Construction (Critical Decision 3). Many acquisitions were started in FY04, and some of the materials will be stored until the building is completed in the second quarter of FY05.

The OMEGA EP laser will be housed in a new facility adjacent to the OMEGA facility. The building, under construction throughout FY04, was funded entirely by the University of Rochester. When completed, it will provide the required stable optical platform, 262 feet long by 82 feet wide, within a clean-room envelope. The 82,000-sq-ft facility will also house ancillary laboratories for construction and operation of the laser. The building construction exterior masonry, windows, loading docks, curbing, and grading were all completed in FY04. Interior work highlights for FY04 include the single-pour, 2000-cu-yd (~8 million lbs) concrete slab to support the laser, installation of the clean-room equipment, installation and certification of the two overhead 10-ton cranes for the laser and target areas, and installation of the laser system infrastructure such as the electrical subsystems, cooling water, and vacuum piping.

The goals of the project did not change in FY04. Principal to the mission is to provide OMEGA with a short-pulse, high-energy backlighting capability for new high-energy-density physics experiments under conditions that also allow the development of backlighting techniques for the NIF. Additionally, the EP laser will provide the capability to carry out integrated fast-ignition experiments on OMEGA using OMEGA's unique cryogenic target implosion capability. Two short-pulse (1- to 100-ps), high-power, high-energy beams will be provided to meet the mission-need requirements. These two beamlines will be completed and coupled to the OMEGA laser by the end of FY07. The OMEGA EP system will have a separate auxiliary target chamber funded through a grant from New York State that will be used during laser start-up and ultimately for independent experiments. The two short-pulse beams will use chirped-pulse amplification (CPA) and NIF multipass architecture to provide irradiation to targets in either the OMEGA or OMEGA EP target chambers. Throughout the design and construction phases, an option of building two additional beamlines and an ultraviolet capability has been preserved. At modest incremental cost, the project's two additional beamlines provide the capability to operate all four beams in long-pulse mode (1 to 10 ns).

Six key optical technologies were identified early in the project as critical to the success of the project. These elements and highlights of FY04 progress mirror the overall progress of the project. These six elements range from leveraging and expanding existing LLE capabilities to adaptation of NIF technology for OMEGA EP requirements:

1. A CPA laser source capable of seeding a NIF-like beamline and greater than 250 mJ at 5 Hz for pre-shot setup. In FY04 the energy, repetition rate, and temporal and spectral characteristics required were demonstrated on a full-scale prototype laser developed at LLE (p. 194). Amplification by optical parametric chirped-pulse amplification (OPCPA) was optimized for the OMEGA EP requirements by tuning the laser pump system. A technique for magnetorheological finishing (MRF) of large-aperture, 1-in.-diam Nd:YLF crystal amplifier rods was developed for the pump laser and transferred to the manufacturer for production.

2. A single-aperture plasma electrode Pockels cell (PEPC), with requirements similar to the NIF PEPC. An LLE-engineered PEPC was manufactured, assembled, and coupled to NIF-like, high-voltage pulsers. Integrated plasma testing started in FY04 in a purpose-built laboratory that will be used to characterize spatially and temporally resolved contrast.

3. An LLE-style amplifier that utilizes a 40-cm-square-aperture laser disk. A prototype amplifier designed, manufactured, and assembled in FY03 was tested in FY04 with over 1000 shots in a spatially and temporally resolved wavefront and small-signal-gain instrument. The performance requirements were met, and production of 36 amplifiers was initiated.

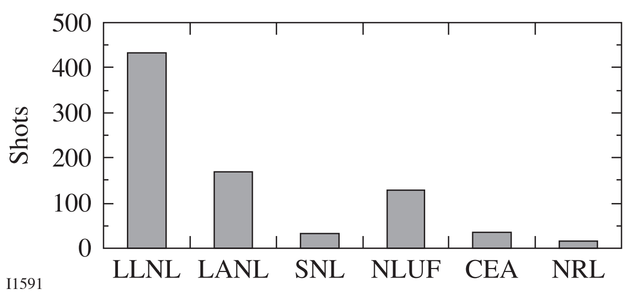
4. Adaptation of the NIF-design deformable mirror (DM) to the OMEGA EP system including wavefront sensing and LLE-developed feedback controls. In FY04 LLE implemented wavefront sensing and mirror control hardware and software that enabled setting the DM to the required wavefront for compensating expected errors from the beamline and compressor systems.

5. High-damage-threshold, large-area, multiplayer dielectric diffraction gratings. LLE played a strong role using unique damage-testing capabilities at 10 ps to aid suppliers in identifying and mitigating processing issues that cause damage to fall below intrinsically possible thresholds. In FY04 the damage thresholds required for greater-than-2-kJ-per-beam operation were demonstrated on sub-aperture samples, and orders were placed with two suppliers for a total of 16 grating tiles.

6. Grating tiling to coherently add the diffracted fields from three gratings so that they behave as one larger monolithic grating (p. 242). A reduced-scale tiled grating compressor and closed-loop control system was demonstrated at LLE. The closed-loop tiling system used interferometric feedback to position grating tiles. Full-scale tiled grating assemblies were designed in FY04 along with a test stand that will validate the production design performance in FY05.

National Laser Users' Facility and External Users' Programs

FY04 was a record year for external user experiments on OMEGA. As reported in the FY04 Laser Facility Report beginning on p. 286, a total of 802 target shots were taken on OMEGA for external users' experiments, accounting for 51.5% of the total OMEGA shots produced this year. External users in FY04 included eight collaborative teams under the National Laser Users' Facility (NLUF) program as well as collaborations led by scientists from the Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Sandia National Laboratory (SNL), Naval Research Laboratory (NRL), and the Commissariat à l'Énergie Atomique (CEA) of France. The number of shots for these external users is shown in the graph below.



1. NLUF Programs

The fiscal year was the second of a two-year period of performance for the nine NLUF projects approved for FY03–FY04 funding and OMEGA shot time. Eight of the nine NLUF campaigns received a total of 127 shots on OMEGA in FY04.

The Department of Energy (DOE) issued solicitations in FY04 for NLUF proposals for work to be carried out in FY05–FY06. DOE raised the available NLUF funding to $1,000,000 for FY04 proposals to accommodate the high level of interest in using OMEGA to carry out experiments of relevance to the National Nuclear Security Agency (NNSA) Stockpile Stewardship Program (SSP).

A total of 16 NLUF proposals were submitted to DOE for consideration for FY05–FY06 support and OMEGA shot allocation. An independent DOE Technical Evaluation Panel reviewed the proposals on 15 June 2004 and recommended that up to 8 of the 16 proposals receive DOE funding and 7 of the 8 teams be approved for shot time on OMEGA in FY05–FY06. The following projects were carried out in FY04:

- *Optical Mixing Controlled Simulated Scattering Instabilities (OMC SSI): Generating Electron Plasma Waves and Ion-Acoustic Waves to Suppress Backscattering Instabilities*
- *Studies of Ion-Acoustic Waves (IAW's) Under Direct-Drive NIF Conditions*
- *Experimental Astrophysics on the OMEGA Laser*
- *Recreating Planetary Core Conditions on OMEGA*
- *Experimental and Modeling Studies of 2-D Core Gradients in OMEGA Implosions*
- *OMEGA Laser Studies of the Interaction of Supernova Blast Waves with Interstellar Clouds*
- *Time Evolution of Capsule* ρR *and Proton Emission Imaging of Core Structure*

2. FY04 LLNL OMEGA Experimental Program

Lawrence Livermore National Laboratory (LLNL) conducted 431 target shots on OMEGA in FY04. Approximately half of the shots were for the High-Energy-Density Science (HEDS) Program, and the other half were for inertial confinement fusion (ICF) experiments. The ICF experiments included gas-filled, cocktail, lined, or foam-filled hohlraums; long-scale-length plasma physics; high-resolution imaging of cores; roughened capsules; and ablator materials studies.

Studies of laser–plasma interaction were done on large-scale-length plasmas created by preheating large gas-filled targets with the main laser. Various experiments, some using a 2ω or 4ω probe beam, were conducted to obtain data on stimulated Raman scattering (SRS), stimulated Brillouin scattering (SBS), and beam propagation as functions of beam-smoothing level. The results show reduced beam spray and backscatter by using increased smoothing on a 2ω probe beam. More crossing-beam power transfer experiments (a form of Brillouin scattering of special interest to the NIF) were performed as a function of polarization state. Thomson scattering was used frequently to measure the electron temperature of these plasmas, while backscattered light (FABS) diagnostics monitored the amount of SBS or SRS. Still other experiments demonstrated the ability to measure the time-resolved spectrum of H- and He-like Ti (5-keV) x rays scattered by free electrons in a hot plasma; careful fits to the data yield temperature and density data. Finally, a hohlraum experiment was conducted to quantify the amount of laser light that, at early times, is refracted from the hohlraum wall directly onto the implosion capsule.

Continued systematic improvements were made in using target-mounted pinholes to image implosion cores at moderately high (>7-keV) energies. Asymmetric core images were obtained at 87× magnification, demonstrating a method for measuring higher-order (up to 6, possibly 8) mode structure in the hohlraum drive.

A first experiment was conducted to look at the effect of DT-fill tubes on an imploded capsule, using a deposited bump on the capsule as a surrogate for the fill tube.

Building on the work on hot hohlraums (see HEDS below), several implosion experiments were conducted using smaller-than-standard (3/4-size) hohlraums. These represented the highest radiation-driven temperature implosions shot on laser facilities, reaching 275 to 285 eV, and producing symmetric cores. In some experiments, DHe^3 supplied by LLE was used as the fuel; DHe^3 fusion proton yields and spectra were recorded and analyzed by MIT.

In collaboration with the University of Nevada, Reno (NLUF), multiple pinhole-imaged and spectrally dispersed data were obtained from indirectly driven, Ar-doped fuel implosions.

Finally, several days of experiments were done in collaboration with LANL and LLE, using direct-drive, DT-filled targets, for the purpose of developing neutron diagnostics. These relatively high-yield shots have indicated that significant background will be present for any diagnostics or electronics that are neutron sensitive.

The other half of the LLNL shots was devoted to high-energy-density-science (HEDS)–relevant experiments. These are summarized as follows:

- Hot hohlraum experiments used hohlraums that were as small as possible to create as-high-as-possible radiation environments. Measurements were made on effective radiation temperature, high-energy ("suprathermal") x rays, and laser–target coupling.

- Equation-of-state (EOS) experiments continued on OMEGA in FY04. These involved VISAR measurements of shock propagation times in various materials. Other experiments focused on creating and using an adiabatic (shockless) drive to smoothly ramp up the pressure for EOS measurements of solid (not melted) materials. Finally, experiments done in collaboration with an NLUF investigator used gases that were precompressed in a diamond anvil cell to explore equations of state relevant to the giant planets.

- OMEGA shots were also used to explore various options for obtaining x-ray point backlighters. It is expected this knowledge will be used on future OMEGA and NIF shots.

- A number of shots were devoted to studying alternative approaches to the standard indirect-drive concept of a simple hohlraum with a single-shell capsule. These included "dynamic hohlraums," where a high-*Z* gas is directly driven and compressed and its resulting x rays are used to drive a second, concentric implosion capsule; and "double shells," where the first driven shell collides with an inner shell, resulting in implosion velocity multiplication.

- The radiation flow campaign continued in FY04, focusing on x-ray propagation through low-density foams.

- A series of experiments were conducted to develop appropriate backlighter sources and detectors to measure the opacity of warm materials. The results of this campaign are expected to be used on experiments in FY05.

- LLNL continued a collaboration with LANL and AWE (United Kingdom) on the "Jets" experiments, looking at large-scale hydrodynamic features.

- Finally, shots onto gas-bag targets were conducted with various mid- to high-*Z* gases, in connection with developing x-ray sources.

3. FY04 LANL OMEGA Experimental Programs

Los Alamos National Laboratory (LANL) fielded a wide range of direct-drive-implosion experiments in both spherical and cylindrical geometries during FY04. The primary emphasis of these experiments was to measure mixing in convergent geometries to understand basic hydrodynamic behavior that will help validate our inertial confinement fusion (ICF) codes. Direct measurements of the stability of grainy Be were performed as part of the national effort to characterize ignition-capsule ablator materials. Collaborations with LLNL, LLE, and AWE are an important part of LANL's program on the OMEGA laser at LLE. The Astrophysical Jets experiment and the development of the burn-history diagnostic were continued with these collaborating institutions. LANL also fielded its first experiments designed specifically as staging experiments for future execution on the NIF. LANL conducted a total of 168 target shots on OMEGA in FY04.

4. FY04 SNL OMEGA PROGRAMS

SNL carried out 31 target shots on the OMEGA laser in FY04 and also participated in several of the campaigns led by other laboratories. The SNL-led campaigns included the following:

- *Modification of a Laser Hohlraum Spectrum via a Mid-*Z *Wall Liner*
- *The Effectiveness of Mid-*Z *Dopants in Reducing Preheat in Indirect-Drive ICF Ablator Materials*
- *Long-Pulse Au Hohlraum Wall Albedo Measurements*
- *Tests of a VISAR Time-Resolved Hohlraum Temperature Measurement Technique*

5. FY04 NRL Program

As part of a collaborative effort with NRL, a series of 13 OMEGA target shots were taken to investigate the control of laser imprinting.

The objectives of this experiment were to evaluate the impact of laser imprint under conditions similar to ICF-like reactor implosions and to test the effectiveness of controlling imprint from a high-power glass laser with the use of thin, high-*Z*-layer targets.

6. FY04 CEA Program

A total of 32 target shots led by CEA (Commissariat à l'Énergie Atomique, France) were carried out on OMEGA in FY04. The corresponding four experimental campaigns studied (a) laser–plasma interaction (LPI) in long-scale-length plasmas relevant to NIF/LMJ indirect-drive conditions; (b) irradiation symmetry and x-ray conversion efficiency in empty gold hohlraums; (c) production and optimization of multi-keV x-ray sources (performed on LLNL-owned shots); and (d) hydrodynamic instabilities in planar geometry.

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. Twenty faculty from five departments collaborate with LLE's scientists and engineers. Presently 63 graduate students are pursuing graduate degrees at the Laboratory, and LLE is directly funding 45 University of Rochester Ph.D. students through the Horton Fellowship program. The research includes theoretical and experimental plasma physics, high-energy-density physics, x-rays 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 sixty-eight students have earned Ph.D. degrees at LLE since its founding. An additional 14 graduate students, 6 undergraduate students, and 2 postdoctoral and 7 faculty positions from other universities were funded by NLUF grants. The most recent University of Rochester Ph.D. graduates and their thesis titles include the following:

Bentley, Sean J.	"*Use of Coherently Prepared Media for Efficient, High-Fidelity Frequency Conversion of Electromagnatic Radiation*"
Chen, Deqing	"*Multi-Level Shared State and Application-Specific Coherence Models*"
Rencuzogullari, Umit	"*Dynamic Resource Management for Parallel Applications in an Autonomous Cluster of Workstations*"
Xu, Ying	"*Optical Studies of Ultrafast Carrier Dynamics in High Temperature Superconductors*"
Zhang, Jim	"*Ultrafast Nbn Superconducting Single-Photon Detectors for Non-Invasive CMOS Circuit Testing*"
Zheng, Xuemei	"*Ultrafast Characterization of Optoelectronic Devices and Systems*"
Bhattacharya, Mishkatul	"*Forbidden Transitions in a Magneto-Optical Trap*"

Approximately 66 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 laser development, materials, and optical-thin-film coating laboratories; and 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.

In addition, LLE directly funds research programs within the MIT Plasma Science and Fusion Center, the State University of New York (SUNY) at Geneseo, and the University of Wisconsin. These programs involve a total of approximately 5 graduate students, 13 undergraduate students, and 3 faculty from other universities.

For the past 16 years LLE has run a Summer High School Student Research Program (p. 282). This year 16 high school juniors spent eight weeks performing individual research projects. A staff scientist or an engineer individually supervises each student. 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 2004, LLE presented its seventh William D. Ryan Inspirational Teacher Award to Mr. Claude Meyers, a former Physics Teacher at Greece Arcadia 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. David Bowen, a participant in the 2001 Summer Program, nominated Mr. Meyers.

Robert L. McCrory
Director and CEO