Executive Summary

The fiscal year ending September 2010 (FY10) concluded the third year of the third five-year renewal of Cooperative Agreement DE-FC52-08NA28302 with the U.S. Department of Energy (DOE). This annual report summarizes progress in inertial fusion research at the Laboratory for Laser Energetics (LLE) during the past fiscal year including work on the National Ignition Campaign (NIC). It also reports on LLE's progress on laboratory basic science research; laser, optical materials, and advanced technology development; operation of OMEGA and OMEGA EP for the NIC and high-energy-density (HED) campaigns, the National Laser Users' Facility (NLUF), and for other external users; and programs focusing on the education of high school, undergraduate, and graduate students during the year.

Progress in Inertial Confinement Fusion Research

One of the principal missions of the University of Rochester's Laboratory for Laser Energetics (LLE) is to conduct research in inertial confinement fusion (ICF) with particular emphasis on supporting the goal of achieving ignition on the National Ignition Facility (NIF). This program relies on the full use of the OMEGA 60-beam UV laser as well as the OMEGA EP high-energy, short-pulse laser system. During FY10, a record total of 1823 target shots were taken on the Omega Laser Facility. Within the NIC, LLE plays a lead role in the validation of the performance of cryogenic target implosions, essential to all forms of ICF ignition. LLE is responsible for a number of critical elements within the Integrated Experimental Teams (IET's) supporting the demonstration of indirect-drive ignition on the NIF and is the lead laboratory for the validation of the polar-drive approach to ignition on the NIF. LLE has also developed, tested, and constructed a large number of diagnostics that are being used on the NIF for the NIC. During this past year, progress in the inertial fusion research program continued to be made in three principal areas: NIC experiments; development of diagnostics for experiments on OMEGA, OMEGA EP, and the NIF; and theoretical analysis and design efforts aimed at improving direct-drive–ignition capsule designs and advanced ignition concepts such as fast ignition and shock ignition.

1. National Ignition Campaign Experiments

LLE achieved a fuel areal density of 0.3 g/cm^2 on an OMEGA cryogenic-DT direct-drive capsule driven with a picket pulse at a shell adiabat $\alpha \sim 2$. This represents the highest DT-fuel areal density achieved to date in direct-drive implosions, and the results are a crucial step in validating predictive capabilities of hydrodynamic codes used to design ignition capsules to be used on the NIF. The first article (p. 1) of this Annual Report discusses in detail the achievement of this high-areal-density milestone. A critical challenge of hot-spot–implosion design is controlling the generation of strong shocks while simultaneously accelerating the fuel shell to a high velocity (~3×10^7 cm/s). To avoid preheating the fuel, only shocks with shock strength less than a few million atmospheres (Mbar) can be launched into the cryogenic fuel at the start of an implosion. To avoid, however, break up of the shell caused by Rayleigh–Taylor instabilities, the shell must be driven at pressures exceeding 100 Mbar. The targets that successfully demonstrated high fuel areal density on OMEGA were driven with multiple picket pulses that launched a sequence of shocks of increasing strength in the fuel [multiple-shock (MS) designs].

Understanding the equation of state (EOS) of the materials used in ignition targets is critical to optimizing target performance. Beginning on p. 6, we report on high-precision measurements of the EOS of hydrocarbons at pressures ranging from 1 to 10 Mbar. Precision data resulting from the use of α quartz as an impedance-matching (IM) standard were used to tightly constrain the EOS of polystyrene and polypropylene. Both hydrocarbons were observed to reach similar compressions and temperatures as a function of temperature. The materials were observed to transition from transparent insulators to reflecting conductors at pressures of 1 to 2 Mbar.

The results of experiments on the interaction of high-intensity, short-pulse laser irradiation of small-mass–copper (Cu), wedge-shaped–cavity targets are presented (p. 72). Experimental diagnostics provided spatially and spectrally resolved measurements of the Cu K_α line emission at 8 keV.

The coupling efficiency of short-pulse laser energy into fast electrons was inferred from the x-ray yield for wedge opening angles between 30° and 60° and for *s*- and *p*-polarized laser irradiation. Up to 36±7% coupling efficiency was measured for the narrowest wedge with *p*-polarization. The results are compared with predictions from two-dimensional particle-in-cell simulations.

A report on the scaling of hot-electron generation in high-power, kilojoule-class laser–solid interactions is presented on p. 174. Thin-foil targets were irradiated with high-power (~210-TW), 10-ps pulses focused to intensities of $I > 10^{18}$ W/cm^2 and studied with K-photon spectroscopy. Comparing the energy emitted in K photons to target-heating calculations shows a laser-energy–coupling efficiency to hot electrons of $\eta_{\mathrm{L}\rightarrow\mathrm{e}} = 20\pm10\%$. Time-resolved x-ray–emission measurements suggest that laser energy is coupled to hot electrons over the entire duration of the incident laser drive. Comparison of the K-photon emission data to previous data at similar laser intensities shows that $\eta_{\mathrm{L}\rightarrow\mathrm{e}}$ is independent of laser-pulse duration from 1 ps $\leq \tau_{\mathrm{p}} \leq$ 10 ps.

2. Cryogenic Target Fabrication

Beginning on p. 149 we report on the development of a microfluidics-based, on-chip, electric-field–actuated technique to fabricate cryogenic-foam ICF targets. The electrowetting-on-dielectric and dielectrophoresis effects make it possible to manipulate both conductive and dielectric droplets simultaneously on a substrate. Aqueous and non-aqueous liquid droplets precisely dispensed from two reservoirs on a microfluidic chip are transported and combined to form oil-in-water-in-air or water-in oil-in-air double-emulsion droplets. The dispensing reproducibility is studied as a function of a set of operation parameters. Conditions for spontaneous emulsification for double-emulsion formation are developed in terms of droplet surface energies. This technique has the potential of meeting the high-precision, high-rate, low-cost, compact, low-tritium inventory requirements of future inertial fusion energy reactor systems.

3. Target Diagnostics for OMEGA, OMEGA EP, and the NIF

A critical instrument used to measure compressed fuel areal density (ρR) in highly compressed DT targets is the magnetic recoil spectrometer (MRS). The MRS was developed and implemented on OMEGA as well on NIF by a collaborative team comprised of MIT, LLE, and LLNL scientists and engineers. The fundamental principles and design parameters of this instrument are described in detail beginning on p. 33. The MRS measures the absolute neutron spectrum in the range of 5 to 30 MeV. In high-density target implosions, the fusion neutrons scatter on the deuteron and triton ions of the compressed core and the resulting downshift in the neutron energy can be used to directly infer the core areal density. The OMEGA MRS was used to measure the fuel ρR of cryogenic-DT implosions demonstrating $\rho R \sim 0.3$ g/cm^2. A version of the OMEGA MRS was installed on the NIF in FY10.

Another important diagnostic to characterize the density of highly compressed targets is x-ray radiography. The first radiographs of cryogenic implosions on OMEGA were obtained using short-pulse, K-shell emission-line backlighters driven by the OMEGA EP laser (see p. 128). Simulations show that radiography near peak compression is feasible. The backlighter composition in this set of experiments was chosen so that the emission lines occurred at energies where the opacity profiles of the imploded cores provide a measurable range of optical depth and the specific intensity of the backlighter is capable of overcoming the core self-emission. Simulations of the first measured implosion radiographs were used to assess the implosion performance at times in advance of peak compression. Radial mass distributions were obtained from the radiographs using Abel inversion and the known temperature and density dependence of the free–free opacity of the hydrogen shell. Radiography based on Compton scattering of hard backlight x rays is also being investigated on the Omega Facility as an alternative approach. The relative advantages of both methods of radiography are compared in this article.

An LLE team partnered with Physikalisch Technische Bundesanstalt, Braunscheig, Germany, to develop a gated liquid-scintillator–based neutron detector to be used for fast-ignitor experiments and down-scattered neutron measurements (p. 145). The detection of neutrons in such experiments is very challenging since it requires the neutron-detection system to recover within 50 to 500 ns from a high background signal many orders of magnitude stronger than the signal of interest. The liquid-scintillator–based detector uses a gated microchannel photomultiplier that suppresses the high background signal and an oxygen-enriched liquid scintillation material that eliminates the afterglow present in conventional plastic scintillators.

The performance of a charge-injection device in the high-energy–neutron environment of laser-fusion experiments has been studied (p. 159). Charge-injection devices (CID's) are being used to image x rays in laser-fusion experiments on the OMEGA Laser System, up to the maximum neutron yields generated (~10^{14} DT). The detectors are deployed in x-ray pinhole cameras and Kirkpatrick–Baez microscopes. The neutron fluences ranged from ~10^7 to ~10^9 neutrons/cm^2, and useful x-ray images were obtained even at the highest fluences. At the NIF, CID cameras are intended for use as a supporting means of recording x-ray images. The results of this work predict that x-ray images should be obtainable on the NIF at yields up to ~10^{15}, depending on distance and shielding.

Neutron imaging is used in ICF experiments to measure the core symmetry of imploded targets. Liquid bubble chambers have the potential to obtain higher-resolution images of the targets for a shorter source-to-target distance than typical scintillator arrays. A theoretical model that describes the mechanism of bubble formation for Freon 115 as the active medium in a liquid bubble chamber is presented (p. 50). The bubble-formation model shows that the size of the critical radius for the nucleation process determines the mechanism of bubble formation and the sensitivity of the active medium for the 14.1-MeV incident neutrons resulting from ICF implosions. The bubble-growth mechanism is driven by the excitation of the medium electronic levels and not by electrons ejected from the medium's atoms as occurs in the bubble chambers used to detect charged particles. The model accurately predicts the neutron-induced bubble density measured on OMEGA with liquid bubble chambers and gel detectors.

4. Theoretical Design and Analysis

In ICF, a shell of cryogenic DT is accelerated inward by either direct laser irradiation or by x rays produced by heating a high-*Z* enclosure (a hohlraum). At the stagnation of this implosion, the compressed fuel is ignited by a central hot spot surrounded by a cold, dense shell. Ignition occurs when the alpha-particle heating of the hot spot exceeds all the energy losses. To measure progress toward ignition, we developed the metric described beginning on p. 22. This ignition condition is derived in terms of measurable parameters: the areal density, the ion temperature, and the ratio of measured neutron yield to the calculated clean, perfect implosion yield (YOC).

Beginning on p. 111 we report on the use of 2-D *DRACO* simulations to systematically investigate the impact of nonuniformities seeded by target and laser perturbations on neutron yield in cryogenic-DT implosions. Two sources of nonuniformity accounted for the observed neutron-yield reduction according to the *DRACO* simulations: target offset from the target chamber center and laser imprinting. The integrated simulations for individual shots reproduce the experimental YOC ratio to within a factor of ~2. Typically, the YOC in OMEGA cryogenic experiments is ~5%. The simulations suggest that YOC can be increased to the ignition hydro-equivalent level of 15% to 20% (with neutron-averaged ρR in the range of 0.2 to 0.3 g/cm^2) by maintaining a target offset of less than 10 μm and employing beam smoothing by spectral dispersion (SSD).

Crossed-beam energy transfer in ICF implosions on OMEGA is discussed in an article beginning on p. 79. Radiative–hydrodynamic simulations of implosion experiments on the OMEGA Laser System show that energy transfer between crossing laser beams can significantly reduce laser absorption. A new quantitative model for crossed-beam energy transfer has been developed, allowing one to simulate the coupling of multiple beams in the expanding corona of implosion targets. Scattered-light and bang-time measurements show good agreement with predictions of this model when nonlocal thermal transport is used. The laser absorption can be increased by employing two-color light, which reduces the crossed-beam energy transfer.

An extension of the fully kinetic, reduced-description, particle-in-cell (RPIC) methodology to model two-plasmon-decay (TPD) instability is presented in an article beginning on p. 88. This work was motivated by the recent resurgent interest in suprathermal electron generation by TPD instability in direct-drive laser fusion. RPIC provides a computationally efficient, fully kinetic simulation tool, especially in nonlinear regimes where Langmuir decay instability (LDI) is a dominant saturation mechanism. This RPIC methodology is an extension of the modeling of laser–plasma instabilities in underdense plasmas reported previously. The relationship between RPIC and the extended Zakharov model previously used for TPD instability is explored theoretically and tested in simulations. The modification of electron-velocity distribution—in particular, the generation of hot electrons—as calculated in RPIC leads to weakening of the wave turbulence excited by TPD instability compared to the Zakharov model predictions. However, the locations in wave vector space of important spectral features, e.g., arising from the LDI, of the nonlinear wave fluctuations are exactly the same in the two approaches. New results involving two oblique, overlapping laser beams, a common geometrical feature in direct-drive schemes, are presented. The two laser beams can cooperatively excite common primary Langmuir waves, which initiate the LDI process.

An article beginning on p. 44 presents the results of a collaboration between scientists from LLE and the University of California, Berkeley, on the development of a first-principles equation-of-state (FPEOS) table for deuterium using the path-integral Monte Carlo method. Accurate knowledge about the equation of state (EOS) of deuterium is critical to ICF. Low-adiabat ICF implosions routinely access strongly coupled and degenerate plasma conditions. The FPEOS table covers typical ICF fuel conditions at densities ranging from 0.002 g/cm^3 to +1600 g/cm^3 and temperatures of 1.35 eV to 5.5 keV. Discrepancies in internal energy and pressure have been found in strongly coupled and degenerate regimes with respect to *SESAME* EOS. Hydrodynamics simulations of cryogenic ICF implosions using the FPEOS table have indicated significant differences in peak density, areal density (ρR), and neutron yield relative to *SESAME* simulations. The FPEOS simulations result in better agreement of compression ρR with experiments.

Lasers, Optical Materials, and Advanced Technology

We report on a grating-inspection system and a damage-analysis method developed to measure *in-situ* laser-induced damage on the 1.4-m-long tiled-grating assembly of the OMEGA EP pulse compressor during a 15-ps, 2.2-kJ energy ramp (p. 27). The beam fluence at which significant damage growth occurred was determined. This is the first report on beam fluence versus laser-induced–damage growth of meter-sized multilayer-dielectric-diffraction gratings. This result was correlated to the damage-probability measurement conducted on a small grating sample and is consistent with the fluence corresponding to 100% damage probability.

An article on p. 165 reports on the development and implementation of a grating inspection system for large-scale (1.4-m aperture) multilayer-dielectric gratings on the OMEGA EP short-pulse laser system. The grating inspection system (GIS) is fully integrated within the vacuum grating compressor and enables one to carry out inspections while the compressor chamber is under vacuum. Damage is detected by imaging scattered light from damage sites on the grating surface. Features as small as 250 μm can be identified with this system.

Switchable gas permeation membranes have been fabricated (p. 63) in which a photoswitchable, low-molecular-weight liquid crystalline (LC) material acts as the active element. Liquid crystal mixtures are doped with mesogenic azo dyes and infused into commercially available track-etched membranes with regular cylindrical pores (0.40 to 10.0 μm). Tunability of mass transfer can be achieved through a combination of (1) LC/mesogenic dye composition, (2) surface-induced alignment, and (3) reversible photoinduced LC-isotropic transitions. Photoinduced isothermal phase changes in the imbibed material afford large and fully reversible changes in the permeability of the membrane to nitrogen. Both the LC and photogenerated isotropic states demonstrate a linear permeability/pressure relationship, but they show significant differences in their permeability coefficients. Liquid crystal compositions can be chosen such that the LC phase is more permeable than the isotropic—or vice versa—and can be further tuned by surface alignment. Permeability switching response times are 5 s, with alternating UV and >420-nm radiation at an intensity of 2 mW/cm^2 being sufficient for complete and reversible switching. Thermal and kinetic properties of the confined LC materials are evaluated and correlated with the observed permeation properties. This is the first demonstration of reversible permeation control of a membrane with light irradiation.

Scientists from LLE, the State University of New York (SUNY) at Stony Brook, and Power Photonic Corp. co-authored a report on highly stable, room-temperature, mid-IR, GaSb-based laser diodes (p. 85). Such laser diodes have been characterized at various temperatures and driver currents. Up to 54 mW of output laser power was demonstrated in a 3150- to 3180-nm–wavelength range with <20-nm FWHM spectral width.

We report on a measurement of the self-phase-modulation–induced bandwidth in a 30-kJ–class laser-amplifier chain (p. 179). Self-phase modulation (SPM) in a multikilojoule laser system was detected spectroscopically and correlated with the time derivative of the intensity measured at the output of the system. This correlation provides an empirical relationship that makes it possible to rapidly determine the magnitude of the SPM being generated using measured experimental data. This empirical relationship was verified by modeling the propagation of an optical pulse in the laser-amplifier chain to predict both pulse shape and the SPM.

Work on large-aperture plasma-assisted deposition of ICF laser coatings is presented beginning on p. 184. Plasma-assisted electron-beam evaporation leads to changes in the crystallinity, density, and stresses of thin films. A dual-source plasma system was developed that provides stress control of large-aperture, high-fluence coatings used in vacuum for substrates 1 m in aperture.

A system was developed (p. 192) to conduct on-shot focal-spot measurements on OMEGA EP using phase-retrieval–enhanced wavefront measurements. Target-plane intensities of the short-pulse beamlines of OMEGA EP were characterized using the focal-spot diagnostic (FSD), an indirect wavefront-based measurement. Phase-retrieval methods were employed using on-shot and off-line far-field measurements to improve the on-shot wavefront measurements and yield more-accurate, repeatable focal-spot predictions. Incorporation of these techniques has resulted in consistently high (>90%) correlation between the FSD focal-spot predictions and direct far-field fluence measurements in the target chamber in low-energy testing.

National Laser Users' Facility and External Users' Programs

Under the facility governance plan that was implemented in FY08 to formalize the scheduling of the Omega Facility as a National Nuclear Security Agency (NNSA) facility, Omega Facility shots are allocated by campaign. The majority (~65%) of the FY10 target shots were allocated to the NIC conducted by integrated teams from the national laboratories and LLE and to the high-energy-density campaigns conducted by teams led by scientists from the national laboratories.

During FY10 30% of the facility shots in were allocated to basic science experiments. Half of these shots were conducted for university basic science under the National Laser Users' Facility (NLUF) Program, and the remaining shots were allotted to the Laboratory Basic Science (LBS) Program comprising peer-reviewed basic science experiments conducted by the national laboratories and LLE/FSC.

The Omega Facility is also being used for several campaigns by teams from the Commissariat à l'énergie atomique (CEA) of France, and the Atomics Weapons Establishment (AWE) of the United Kingdom. These programs are conducted on the facility on the basis of special agreements put in place by the DOE/NNSA and the participating institutions.

During FY10 facility users included 11 collaborative teams participating in the NLUF Program; 12 teams led by LLNL and LLE scientists participating in the LBS program; many collaborative teams from the national laboratories conducting experiments for the NIC; investigators from LLNL and LANL conducting experiments for high-energy-density–physics programs; and scientists and engineers from CEA and AWE.

1. NLUF Programs

In FY10, DOE issued a solicitation for NLUF grants for the period of FY11–FY12. A total of 15 proposals were submitted to DOE for the NLUF FY11/12 program. An independent DOE Technical Evaluation Panel reviewed the proposals and recommended that 11 proposals receive DOE funding and 31 days of shot time be allocated on OMEGA in each of FY11 and FY12. Table I lists the successful NLUF proposals.

Table I: Approved FY11 and FY12 NLUF proposals.

Principal Investigator	Institution	Project Title
F. N. Beg	University of California, Berkeley	Systematic Study of Fast-Electron Transport in Imploded Plasmas
R. P. Drake	University of Michigan	Experimental Astrophysics on the OMEGA Laser
T. Duffy	Princeton University	Ramp Compression for Studying Equations of State, Phase Transitions, and Kinetics on OMEGA
R. Falcone	University of California, Berkeley	Detailed *In-Situ* Diagnostics of High-*Z* Shocks
P. Hartigan	Rice University	Clumpy Environments and Interacting Shock Waves: Realistic Laboratory Analogs of Astrophysical Flows
R. Jeanloz	University of California, Berkeley	Recreating Planetary Core Conditions on OMEGA
K. Krushelnick	University of Michigan	Intense Laser Interactions with Low-Density Plasma Using OMEGA EP
R. Mancini	University of Nevada, Reno	Investigation of Hydrodynamic Stability and Shock Dynamics in OMEGA Direct-Drive Implosions Using Spectrally Resolved Imaging
R. D. Petrasso	Massachusetts Institute of Technology	Charged-Particle Probing of Inertial Confinement Fusion Implosions and High-Energy-Density Plasmas
A. Spitkovsky	Princeton University	Collisionless Shocks in Laboratory High-Energy-Density Plasmas
R. Stephens	General Atomics	Investigation of Laser to Electron Energy Coupling Dependence on Laser Pulse Duration and Material Composition

FY10 was the second of a two-year period of performance for the NLUF projects approved for the FY09–FY10 funding and OMEGA shots. Eleven NLUF projects were allotted Omega Facility shot time and conducted a total of 197 target shots on the facility. Brief summaries of this work may be found beginning on p. 229.

2. Laboratory Basic Science Programs

In FY10, LLE issued a solicitation for LBS proposals to be conducted in FY11. A total of 23 proposals were submitted. An independent review committee reviewed the proposals and recommended that 16 proposals receive 29 shot days on the Omega Laser Facility in FY11. Table II lists the successful LBS proposals.

Eleven LBS projects were allotted Omega Facility shot time and conducted a total of 303 target shots on the facility in FY10. Brief summaries of the FY10 LBS work may be found beginning on p. 245 of this report.

3. FY10 LLNL Omega Facility Programs

In FY10, LLNL conducted several campaigns on the OMEGA and OMEGA EP Laser Systems. LLNL-led teams conducted 301 target shots on the OMEGA laser and 96 target shots on OMEGA EP. Approximately 40% of all the shots supported the NIC. The remainder of the shots were conducted for the high-energy-density–physics (HEDP) program.

The objectives of the LLNL-led NIC campaigns on the Omega Facility included the following:

- *Reactivation of the 4ω Thomson-scattering diagnostics*
- *Study of bremsstrahlung backlighters for Compton radiography of ICF implosions*
- *Characterization of shell adiabat of spherically imploded inertial fusion targets using x-ray Thompson scattering*
- *High-resolution measurements of velocity nonuniformities created by microscopic perturbations in NIF ablator materials*
- *Equation-of-state measurements of Ge-doped CH*
- *Validation of the Compton radiography diagnostic platform for ICF experiments*
- *Experiments to study the physical properties (thermal conductivity) of shocked fusion fuels*
- *Characterization of hard x-ray sensitivity of MCP-based gated imagers*

Table II: Approved FY10 LBS proposals.

Principal Investigator	Institution	Project Title
H. Chen	LLNL	Exploring Pair Plasma and its Applications Using OMEGA EP
S. X. Hu	LLE	Charge-Particle Stopping Power in Warm Dense Plasmas
R. Betti	LLE/FSC	Shock-Ignition Experiments on OMEGA
I. V. Igumenshchev	LLE	Investigation of Self-Generated Electromagnetic Fields in Directly Driven ICF Implosions Using Proton Radiography
D. G. Hicks	LLNL	Multi-Megabar Ramp Compression: Studies Using X-Ray Absorption Fine Structure
R. A. Kritcher	LLNL	Capsule Adiabat Measurements with X-Ray Thomson Scattering
P. K. Patel	LLNL	Electron Source Characterization for Cone-Guided Fast Ignition
S. P. Regan	LLE	Diagnosing P, ρ, n_e, T_e, Z of H/He, CH_4, and NH_3 Warm Dense Matter
G. Fiksel	LLE	Laser-Driven Magnetic-Flux Compression Experiments on OMEGA
V. A. Smalyuk	LLNL	Measurement of Ablative Rayleigh–Taylor Instability in Deeply Nonlinear Regime
R. Smith	LLNL	Measurement of Nucleation and Growth of the Fe α-to-ε Phase Transformation
B. Maddox	LLNL	Ultrahigh Pressure Lattice Dynamics in High-Z Metals
H. S. Park	LLNL	Astrophysical Collisionless Shock Generation in Laser-Driven Experiments
O. Hurricane	LLNL	Measurements of Linear, Nonlinear, and Turbulent-Mixing Regimes in Kelvin–Helmholtz Instability in the Subsonic Regime
C. Stoeckl	LLE	Fast-Electron Transport in Solid Density Matter
J. M. McNaney	LLNL	Short-Pulse-Laser–Based Neutron Resonance Spectrometry

- *Characterization of plasma conditions at the laser entrance hole (LEH) of a gas-filled hohlraum using Thomson scattering*
- *Validation of the modeling of multibeam scattering occurring in NIC targets*
- *Measurements of the plasma conductivity by means of collective x-ray Thomson scattering*

The LLNL-led HED campaigns covered five main areas of research:

1. *Material dynamics and equation of state*
   a. *Quasi-isentropic compression experiments (ICE) for material properties such as strength, equation of state, phase, and phase-transition kinetics under high pressure*
   b. *Platform development using radiographic measurements of instability growth in Ta to infer material strength using the joint OMEGA–OMEGA EP configuration*
   c. *Properties of shocked CH and Si aerogel foams used in HED experiments*
   d. *The equation of state of a CO_2 mixture along the Hugoniot*
   e. *Initial experiments to develop an experimental platform to measure the melt and resolidication of Sn*
2. *Opacity*
   a. *Opacity studies of high-temperature plasmas under LTE conditions*
   b. *Initial experiments to compare short- and long-pulse techniques to heat materials to high temperature for opacity data*
3. *Hydrodynamics*
   a. *Measurements of the Kelvin–Helmholtz instability in laser-driven shock tubes*
   b. *The hydrodynamic evolutions of high-Mach-number copper-foam jets*
4. *X-ray sources applications*
   a. *Development of multi-keV x-ray sources for radiography and for the study of material response in samples*
5. *Diagnostic technique development*
   a. *Development of a target-mounted turning mirror for use with the VISAR diagnostic*
   b. *Demonstration of ultrafast temperature and density measurements with x-ray Thomson scattering from short-pulse-laser–heated matter*
   c. *Comparison of short- and long-pulse–generated x-ray backlighters*
   d. *Development of diffraction (white light Laue and powder) to measure the structure of solids (Ta, Fe, Sn)*

Brief summaries of the LLNL-led experiments may be found beginning on p. 255 of this report.

4. FY10 LANL Omega Facility Programs

In FY10, Los Alamos National Laboratory (LANL) executed 131 shots on the OMEGA Laser and 32 shots on the OMEGA EP Laser. LANL had three instruments qualified for use on OMEGA EP. They are the NIF 5 spectrometer, the target-heating Verdi laser (THVL), and the Thomson parabola ion energy (TPIE) diagnostic.

LANL experiments contributed to the NIC in the following areas:

- *Studies of the EOS of plastic ablators*
- *New experimental methods for determining the areal density of imploded ICF capsules using 4.44-MeV $^{12}C(n,n')$ γ rays*
- *Demonstration of NIF components of the neutron imaging system*

HED campaigns included the following:

1. *Measurement of a supersonic radiation wave*
2. *Measurement of capsule yield in the presence of high-Z dopants*
3. *DT reaction product branching ratio measurements*
4. *Energetic ion generation from hemispherical targets*
5. *Development of x-ray sources for phase-contrast imaging*

The LANL-led experiments are summarized beginning on p. 278.

5. FY10 CEA Omega Facility Experiments

CEA-led teams conducted 62 target shots on OMEGA during FY10. The experiments included ablator-preheat characterization, Rayleigh–Taylor (RT) growth measurements, and rugby hohlraum characterization. The CEA work is summarized beginning on p. 288.

This year marked the tenth year of continuous collaborations between CEA and LLE on experiments conducted on the Omega Facility. During this period, more than 500 Omega Facility target shots have been conducted in collaborations involving the two institutions. The results of this past decade of collaboration have been very successful and will contribute significantly to demonstrating ICF ignition.

6. FY10 AWE Omega Facility Programs

AWE teams led experiments on three shot days of the OMEGA laser. The work included an investigation of asymmetrically driven hohlraums (two days) and a Laue-diffraction study of the dynamics of shocked Ta crystals (one day). A total of 37 shots were taken for AWE in FY10. The AWE experiments are summarized beginning on p. 291.

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During FY10, the Omega Laser Facility conducted a record total of 1823 target shots on the OMEGA (1343 target shots) and OMEGA EP (480 target shots) lasers (see Tables 124.III and 124.IV on p. 226). Nearly 46% of the total shots were taken for or in support of NIC. External users accounted for ~63% of the total Omega Facility target shots in FY10 (64.4% of OMEGA and 60.4% of OMEGA EP target shots).

Many modifications were made to the OMEGA laser to improve low-adiabat direct-drive cryogenic implosion performance. OMEGA conducted 38 DT spherical cryogenic target shots and 40 planar cryogenic target shots in support of shock-timing experiments. The OMEGA Availability and Experimental Effectiveness averages for FY10 were 93% and 94%, respectively.

OMEGA EP was operated extensively in FY10 for a variety of users. A total of 308 short-pulse IR shots were conducted. Of these, 232 target shots were taken into the OMEGA EP target chamber and 76 joint shots were taken into the OMEGA target chamber. The Availability and Experimental Effectiveness for OMEGA EP averaged 86% and 94%, respectively.

Several major modifications were implemented on the Omega Facility during FY10:

1. Three-color-cycle (3CC) beam smoothing was implemented on the OMEGA laser to improve the picket-pulse pointing performance.

2. The OMEGA pulse-shaping system was augmented with facility modifications in the temperature and humidity controls of the Driver Electronics Room to improve the temporal shape stability.

3. A new short-pulse timing diagnostic was implemented and calibrated on OMEGA EP. The pulse-shape measurement diagnostic (PSM) uses high-bandwidth oscilloscopes and photodiodes to measure short-pulse timing at the output of the grating compressor chamber (GCC).

4. A full complement of 12 multilayer dielectric gratings was acquired from a commercial vendor to improve short-pulse energy performance on one of the OMEGA EP beamlines. It is expected that the operational energy envelope of this beamline will be increased by ~50% to over 1.5 kJ at 10 ps in the coming year.

5. An OMEGA EP focal-spot diagnostic system was implemented. As a result, on-shot target-plane, focal-spot fluence data are now provided for short-pulse shots on OMEGA EP.

6. A temporal contrast diagnostic system was implemented on OMEGA EP.

7. The first two distributed phase plates were deployed on OMEGA EP.

8. Vacuum antechambers for the backlighter and sidelighter off-axis parabolas (OAP's) were deployed on the OMEGA EP target chamber to facilitate storage of these focusing optics when they are not in use.

9. Two new ten-inch manipulators were installed on the OMEGA EP target chamber, increasing the non-fixed diagnostic capability of the system by 40%.

Education

As the only major university participant in the National ICF Program, education continues to be an important mission for the Laboratory. Laboratory education programs span the range of high school (p. 297) to graduate education.

1. High School Student Program

During the summer of 2010, 16 students from Rochester-area high schools participated in the Laboratory for Laser Energetics' Summer High School Research Program. The goal of this program is to excite a group of high school students about careers in the areas of science and technology by exposing them to research in a state-of-the-art environment. Too often, students are exposed to "research" only through classroom laboratories, which have prescribed procedures and predictable results. In LLE's summer program, the students experience many of the trials, tribulations, and rewards of scientific research. By participating in research in a real environment, the students often become more excited about careers in science and technology. In addition, LLE gains from the contributions of the many highly talented students who are attracted to the program.

The students spent most of their time working on their individual research projects with members of LLE's technical staff. The projects were related to current research activities at LLE and covered a broad range of areas of interest including experimental diagnostic development, computational modeling of implosion physics, laser physics, experimental and theoretical chemistry, materials science, cryogenic target characterization, target vibration analysis, and computer control systems (see Table 124.II on p. 224).

The program culminated on 25 August with the "High School Student Summer Research Symposium," at which the 16 students presented the results of their research to an audience including parents, teachers, and LLE staff. The students' written reports will be made available on the LLE Web site.

Two hundred and sixty-five high school students have now participated in the program since it began in 1989. This year's students were selected from a record 80 applicants.

At the symposium, LLE presented its 14th annual William D. Ryan Inspirational Teacher Award to Mr. Bradley Allen, AP Physics teacher at Brighton Senior High School. This award is presented to a teacher who motivated one of the participants in LLE's Summer High School Research Program to study science, mathematics, or technology and includes a $1000 cash prize.

Teachers are nominated by alumni of the summer program. Mr. Allen was nominated by Nicholas Harvest Zhang and Aaron Van Dyne, participants in the 2009 Summer Program.

2. Undergraduate Student Programs

Approximately 31 undergraduate students participated in work or research projects at LLE this past year. Student projects include operational maintenance of the OMEGA Laser Facility; work in laser development, materials, and optical-thin-film–coating laboratories; computer programming; image processing; and diagnostics 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.

3. Graduate Student Programs

Graduate students are using the OMEGA Facility as well as other LLE facilities for fusion and high-energy-density physics research and technology development activities. These students are making significant contributions to LLE's research program. Twenty-five faculty from the five University academic departments collaborate with LLE scientists and engineers. Presently, 82 graduate students are involved in research projects at LLE, and LLE directly sponsors 38 students pursuing Ph.D. degrees via the NNSA-supported Frank Horton Fellowship Program in Laser Energetics. Their research includes theoretical and experimental plasma physics, high-energy-density physics, x-ray and atomic physics, nuclear fusion, ultrafast optoelectronics, high-power-laser development and applications, nonlinear optics, optical materials and optical fabrication technology, and target fabrication.

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 6 graduate students, 25 to 30 undergraduate students, and 10 faculty members.

Robert L. McCrory
Director, Laboratory for Laser Energetics
Vice Provost, University of Rochester