Executive Summary

The fiscal year ending September 2011 (FY11) concluded the fourth 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 other external users; and programs focusing on the education of high school, undergraduate, and graduate students during the year.

Progress in Inertial Confinement Fusion (ICF) Research

One of LLE's principal missions 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 FY11, a total of 1805 target shots were taken at the Omega Laser Facility. The OMEGA Laser System operated reliably and returned publishable scientific data for numerous campaigns. The largest fraction of experiments, more than 40% of all the shots, were conducted for the NIC. OMEGA operated with Availability and Experimental Effectiveness averages for FY11 of 93% and 96%, respectively.

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 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 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 in FY11

In this volume, we report on experiments that were conducted on OMEGA to measure the velocity and timing of multiple converging shock waves inside spherical targets filled with liquid (cryogenic) deuterium (p. 1). The results show that shock timing can be measured to better than the ±50-ps timing precision required for ignition targets. The technique was applied to full-scale experiments to tune hohlraum-driven ignition targets on the NIF.

Pioneering experiments conducted on OMEGA by a collaborative team led by scientists from MIT's Plasma Science and Fusion Center (PSFC) and comprised of LLE, LLNL, and General Atomics (GA) scientists obtained proton radiographic images of gas-filled hohlraum-driven implosions showing the dynamics of the interior of the hohlraums including inhibition of plasma-jet formation and the mitigation of plasma stagnation on the hohlraum axis (p. 7). The results demonstrated the important roles of spontaneously created magnetic and electric fields in the hohlraum dynamics and capsule implosions and provided insight into the effects of the fill gas on x-ray–driven implosions.

In a collaborative experiment led by scientists from LLE along with scientists from LLNL, GA, Sandia National Laboratories (SNL), Los Alamos National Laboratory (LANL), and the University of Nevada, Reno, the hydrodynamic-instability–induced mixing of ablator material into the hot spot of ignition-scale ICF implosions was measured with x-ray spectroscopy on NIF implosion experiments (p. 145). The experimentally inferred values of hot-spot–mix mass, based on the absolute spectral brightness of the emergent Ge K-shell emission, ranged from 2 to 400 ng. Most implosions were measured to have less than 75 ng of hot-spot mix, consistent with the requirements for ignition.

Measurements of hot-electron generation by the two-plasmon–decay instability (TPD) are reported in an article beginning on p. 151. The OMEGA EP ultraviolet laser beams provide the high energy (9 kJ) necessary to produce overlapped laser intensities of 7×10^{14} W/cm^2 in large, 1-mm-diam laser spots. These laser conditions produced 2.5-keV coronal electron temperatures with density scale lengths at $n_{cr}/4$ of $\sim 400\ \mu$m in CH plasmas. The total number of hot electrons was measured to increase exponentially over nearly four orders of magnitude and the hot-electron temperature increased from 30 kev to 110 keV. These results compare well with a new TPD model designed to provide a physics-based predictive capability for TPD at ignition conditions.

In this volume, we report on an OMEGA experiment carried out by a collaborative team led by MIT-PSFC, LLE, and LLNL that for the first time measured the differential cross section for the elastic neutron–triton (n–^{3}H) and neutron–deuteron (n–^{2}H) scattering at 14.1 MeV using an inertial confinement facility (p. 151). In these experiments, carried out by simultaneously measuring elastically scattered ^{3}H and ^{2}H ions from a deuterium–tritium gas-filled ICF capsule implosion, the differential cross section for the elastic n–^{3}H scattering was obtained with significantly higher accuracy than achieved in previous accelerator experiments. The results compare well with calculations that combine the resonating group method with an *ab initio* no-core model, which demonstrates that recent advances in *ab initio* theory can provide an accurate description of light-ion reactions.

The results of direct-drive, Rayleigh–Taylor (RT) growth experiments conducted in planar cryogenic, liquid deuterium (D_2) targets on the OMEGA laser are reported (p. 157). These are the first RT measurements in deuterium at conditions relevant to ICF using a mass-preimposed initial modulation. The measured modulation optical depths are in agreement with the 2-D hydrodynamic code *DRACO* using flux-limited local thermal transport, providing an important step in the experimental validation of simulations for direct-drive ignition.

2. Theoretical Design and Analysis

A report co-authored by scientists from LLE, Lodestar Research Corp., and the University of California, San Diego, describes the dynamics of hot-electron heating in direct-drive–implosion experiments caused by TPD instability (p. 66). TPD instability was identified as a potential source of target preheat in direct-drive experiments on OMEGA, and a physical model of electron heating has been developed that relies on extended Zakharov simulations to predict the nonlinearly saturated Langmuir wave spectrum. Because of the relatively low areal density of the targets during the time of TPD instability, hot-electron recirculation and reheating are potentially important effects. These effects were modeled by using a particular form of boundary conditions on the test-particle trajectories. Adoption of these boundary conditions was shown to lead to an increase in the computed hot-electron temperature by a factor of 3.

An article beginning on p. 109 describes how a fully kinetic reduced particle-in-cell method, utilizing novel diagnostics, has been applied to simulations of TPD instability in inhomogeneous plasma for parameters consistent with recent direct-drive experiments. This work is the result of a collaboration among scientists from LLE, Lodestar Research Corp., the University of California, San Diego, and LANL. The nonlinear saturated state of TPD is one of Langmuir turbulence involving the coexistence of the Langmuir cavitation and collapse, the Langmuir decay instability, and ponderomotive density-profile modification. The saturated state is characterized by very spiky electric fields, and Langmuir cavitation occurs preferentially inside density channels produced by the ponderomotive beating of the crossed laser beams. Statistical analyses show that cavitons follow Gaussian statistics. At times exceeding 10 ps, the excited Langmuir turbulence moves away from the quarter-critical surface to lower densities. The heated electron-distribution function is, in all cases, bi-Maxwellian, with hot-electron temperatures in the range of 60 keV to 100 keV. In all cases considered, Langmuir cavitation and collapse provide dissipation by producing suprathermal electrons that stabilize the system in saturation and drive the Langmuir wave spectrum to the small dissipation scales at the Landau cutoff. The net hot-electron energy flux out of the system is a small fraction (+0.5% to 2%) of the input laser power in these simulations.

Lasers, Optical Materials, and Advanced Technology

Improvements to optimize the long-pulse, on-target energy of the OMEGA EP laser are reported (p. 37). The improvements included the procurement of higher-UV-damage-threshold beam-transport optics, improvements in the quality of the beam near field profiles, and the development of simulation tools to provide rapid prediction of the laser performance during shot operations. The beam's near-field quality was improved by introducing new apodizer designs in two laser stages: (1) angular detuning of the frequency-conversion crystals to reduce UV beam-intensity modulations and (2) the installation of a programmable spatial-light modulator in the laser front end to provide closed-loop correction of the near-field beam amplitude.

The use of photothermal heterodyne imaging (PHI) to evaluate the spatial distribution of absorbers in hafnia nonlayers is reported (p. 25). The metal-oxide layer is the weakest part of the thin-film coating and typically where damage is initiated. Insight into the nature and distribution of damage precursors is valuable to further improve the material's damage resistance. Gold nanoparticles embedded in a silica film were used to determine the system's resolution of ~5-nm particle size and an ~0.5-μm particle separation. PHI images of hafnia films prior to laser irradiation are structureless, pointing to absorber separations much smaller than the spatial resolution of this method. Using PHI data and atomic force microscopy mapping of damage-initiation sites, an upper limit for absorber separation was calculated to be ~0.1 μm. By comparing heterodyne signals for different film thicknesses, it was determined that hafnia/silica interfacial absorption is not a major factor in damage initiation, but the main contribution comes from absorption inside the hafnia film.

The large tunable, terahertz electro-optic (EO) response in cadmium manganese telluride (Cd,Mn)Te single crystals is reported (p. 33). This crystal, known as CMT, is a well-studied semiconductor material because of its stable zinc-blend structure for high-Mn concentrations that provides a wide tuning range of the energy band gap. It exhibits a large magneto-optic Faraday effect and has a very high stopping power making it a great potential for x- and γ-ray detection. The measurements demonstrated CMT's exceptionally large EO Pockels effect and showed that the EO sensitivity can be magnified for a particular probe wavelength using band-gap engineering.

In FY11 we demonstrated a highly efficient pulsed-diode–pumped, room-temperature Yb:YAG ceramic laser with a slope efficiency of 78% and an optical-to-optical efficiency of 51% (p. 168). This is the highest slope efficiency for a room-temperature Yb:YAG ceramic laser reported to date. A regenerative amplifier with +15-mJ output energy and fourth-order super-Gaussian beam profile based on this laser has been demonstrated.

The amplification of nanosecond, 1053-nm optical pulses from 15 pJ to 240 nJ by a Yb-doped all-fiber regenerative amplifier (AFRA) has achieved an overall gain of 42 dB (p. 85). This is believed to be the highest AFRA output-pulse energy ever reported. The AFRA is an attractive candidate as a chirped-pulse–amplification (CPA) seed source because of its high output-pulse energy in comparison to seed pulses commonly used in existing CPA systems.

Our work on the suppression of parasitic processes in noncollinear optical parametric amplifiers (NOPA) for walk-off and non-walk-off compensating configurations is reviewed beginning on p. 90. Modeling shows that the second-harmonic generation of the signal can reduce the NOPA output energy by 10%. Quantitative measurements on an ultra-broadband, few-cycle NOPA support these findings in the walk-off compensating case, and the effect is reduced by an order of magnitude in the non-walk-off compensating case. A detailed phase-matching analysis for the most common nonlinear crystals is presented as a guide for designing NOPA system.

Stress compensation in hafnia/silica optical coatings by the inclusion of alumina layers is discussed (p. 100). Hafnia/silica films deposited using electron-beam evaporation tend to exhibit high tensile stresses when used in vacuum or low-relative-humidity environments, resulting in film cracking or crazing. The inclusion of alumina layers within the film stack leads to a compressive overall film stress negating this failure mode in the dry-use environments. A film-stress model incorporating the stress of the individual materials and material thicknesses along with the interfacial film effects was developed to calculate the overall film stress when designing multilayer coatings using alumina since this film stress (compressive) was measured to be very different than the alumina monolayer film stress (tensile). While the slow diffusion of water in alumina films presents some manufacturing and operational challenges, a large-aperture hafnia/silica/alumina polarizer coating was fabricated and installed in the OMEGA EP short-pulse cavity location, eliminating the crazing issue observed with the previous films.

A closed-loop, high-resolution beam-shaping system based on a liquid-crystal-on-silicon (LCOS) spatial-light modulator (SLM) in a multiterawatt laser system and in the OMEGA EP long-pulse front end was demonstrated (p. 113). The closed-loop algorithm is based on the linearity of image transformation between the control device and the measured image, where miscalibration of the linear parameters or blurring of the image affects the stability of the algorithm. One of the main causes of blurring is ascribed to the presence of tilted plates and wedges in the imaging system. These are common elements in complex laser systems. Such effects can be either compensated for or avoided by careful design. The procedure and results of damage-threshold measurement for LCOS-SLM are presented to help determine a safe operation regime for this device in high-power laser systems.

The impact of high-frequency spectral phase modulation on the temporal contrast of ultrafast pulses was investigated (p. 117). Expressions were derived for the low-intensity pedestal produced by optical component surface roughness within pulse stretchers and compressors. Phase noise, added across the near field of a spectrally dispersed beam, produces space–time coupling in the far field or focal plane. The pedestal is swept across an area in the focal plane many times the size of the diffraction-limited spot. Simulations were performed for generic stretchers and compressors that showed fundamentally different forms of temporal contrast degradation at focus.

New wavefront reconstruction algorithms for high-spatial-resolution applications were developed (p. 130). Analyzing wavefront reconstructors in the frequency domain lends new insight into ways to improve frequency response and to understand noise propagation. The mathematical tools required to analyze the frequency domain are first developed for discrete band-limited signals. These tools are shown to improve frequency response in either spatial- or frequency-domain reconstruction algorithms. A new spatial-domain iterative reconstruction algorithm based on the Simpson rule is presented. The previously developed rectangular-geometry band-limited algorithm in frequency domain is adapted to hexagonal geometry, which adds flexibility when applying frequency-domain algorithms. Finally, a generalized analytic error propagation formula is found for different types of reconstructors and compared with numerical simulations.

Femtosecond pump–probe spectroscopy studies of time-resolved optical reflectivity of all-oxide, $YBa_2Cu_3O_7$/$La_{0.7}Sr_{0.3}MnO_3$ superconductor/ferromagnet nano-bilayers are presented (p. 141). The temperature dependence of the nonequilibrium carrier dynamics is investigated down to 4 K. The photoresponse of bilayers has two characteristic relaxation times that are shorter than that of the $YBa_2Cu_3O_7$ film, and their superconducting properties are revealed in sharp peaks near the superconducting transition. The bilayer dynamics cannot be interpreted as an incoherent sum of contributions from the two layers; instead, the results point to an active role of an interface layer, where the electronic charge transfer from $La_{0.7}Sr_{0.3}MnO_3$ to $YBa_2Cu_3O_7$ takes place.

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 Laser Facility as a National Nuclear Security Agency (NNSA) facility, Omega Facility shots are allocated by campaign. The majority (65.1%) of the FY11 target shots were allocated to the NIC conducted by integrated teams from the national laboratories and LLE and to the high-energy-density campaigns (HED) conducted by teams led by scientists from the national laboratories.

In FY11 29% of the facility shots were allocated to basic science experiments. Nearly half of these were conducted for university basic science under the 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/Fusion Science Center (FSC).

The Omega Laser Facility is also being used for several campaigns by teams from the Commissariat à l'Énergie Atomique et aux Énergies Alternatives (CEA) of France and Atomic 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.

The facility users during this year included 11 collaborative teams participating in the NLUF Program; 15 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 HED physics programs; scientists and engineers from the CEA and AWE; and scientists, engineers, and students from the Center for Radiative Shock Hydrodynamics of the University of Michigan.

1. NLUF Program

FY11 was the first of a two-year period of performance for the NLUF projects approved for the FY11–FY12 funding and OMEGA shots. Eleven NLUF projects were allotted Omega Facility shot time and conducted a total of 260 target shots on the facility. Brief summaries of this work may be found beginning on p. 172. Table I lists the approved FY11 and FY12 NLUF proposals.

2. Laboratory Basic Science Programs

In FY11, LLE issued a solicitation for LBS proposals to be conducted in FY12. A record 41 proposals were submitted. An independent review committee reviewed and rank-ordered the proposals; the top-ranked 15 proposals were allotted 28 shot days on the Omega Laser Facility in FY12. Table II lists the successful FY12 LBS 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

FY11 LBS Experiments

Fifteen LBS projects were allotted Omega Facility shot time and conducted a total of 303 target shots on the facility in FY11. Brief summaries of the FY11 LBS work may be found beginning on p. 184 of the report.

3. FY11 LLNL Omega Facility Programs

In FY11, LLNL conducted several campaigns on the OMEGA and OMEGA EP Laser Systems, as well as campaigns that used the OMEGA and OMEGA EP beams jointly. Overall, LLNL led 301 target shots involving OMEGA and 81 target shots involving OMEGA EP (not including LLNL-led shots under the LBS Program). Approximately 35% of the shots (126 OMEGA shots, 10 OMEGA EP shots) supported the NIC. The remainder were dedicated to experiments for HED physics (168 OMEGA shots, 72 OMEGA EP shots). Objectives of the LLNL-led NIC campaigns at OMEGA included the following:

- *Characterization of long-pulse, high-resolution, laser-produced backlighters*
- *4ω Thomson scattering*
- *Neutron-induced backgrounds for ARIANE*
- *Thermal-conductivity measurements at a heated CH/Be interface by refraction-enhanced x-ray radiography*
- *18-keV x-ray Thomson scattering of shock-compressed beryllium and aluminum*
- *High-resolution measurements of velocity nonuniformities created by microscopic perturbations in NIF ablator materials*
- *X-ray Thomson scattering of shock-compressed beryllium on OMEGA EP*
- *Pb Hohlraums*
- *Surrogate mix targets with dual backlighting*

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

1. *Material dynamics and equation of state*
   a. *Kr Hugoniot measurements to 730 GPa*
   b. *Ramped compression of different materials*
   c. *Tin melt*
   d. *Powder x-ray–diffraction measurements of solid Fe and Ta to 570 GPa*
   e. *Hohlraum diffraction*

Table II: Approved FY12 LBS proposals.

Principal Investigator	Affiliation	Project Title
P. M. Celliers	LLNL	Measurement of the Viscosity of Shock-Compressed Fluids: Studies of Water and Silica
H. Chen	LLNL	Exploring Pair Plasma and Its Applications Using OMEGA EP and OMEGA Lasers
G. Fiksel	LLE	Magnetic Field Compression in Spherical Implosions on OMEGA
G. Fiksel	LLE	Magnetic Reconnection in High Energy Density Plasmas in the Presence of an External Magnetic Field
O. A. Hurricane	LLNL	Measurements of Linear, Nonlinear, and Turbulent-Mixing Regimes in Kelvin–Helmholtz Instability in the Subsonic Regime
A. L. Kritcher	LLNL	Nuclear-Atomic-Plasma Interactions in Laser-Produced Plasmas
B. R. Maddox	LLNL	Dislocations and Twinning at High Pressure and Strain Rate on BCC Metals
D. P. McNabb	LLNL	Thermonuclear Reactions in Stellar Plasmas and High Resolution Measurements of Three-Body Breakup in Isobaric Analogue Reactions
H.-S. Park	LLNL	Astrophysical Collisionless Shock Generation by Laser-Driven Laboratory Experiments on OMEGA and OMEGA EP
P. K. Patel	LLNL	Compton Radiography of Cone-in-Shell Implosions for Fast Ignition
S. P. Regan	LLE	Probing Shocked Liquid H, H/He, CH_4, N_2, and NH_3 with Inelastic X-Ray Scattering and Shock Velocity Measurements: Toward the Equation-of-State of Planetary Interiors
J. R. Rygg	LLNL	Extreme Chemistry: Molecular Fluids at Mbar Pressure
V. A. Smalyuk	LLNL	Measurements of Ablative Richtmeyer–Meshkov Instability in Nonlinear Regime
C. Stoeckl	LLE	Spectroscopy of Neutrons Generated Through Nuclear Reactions with Light Ions in Short-Pulse Laser Interaction Experiments
W. Theobald	LLE	Integrated Fast-Ignition Experiments

   f. *Equation of state for foams*
   g. *Gigabar equation of state*
   h. *Double pulse*
   i. *Dynamic and lattice diffraction*
   j. *Tantalum Rayleigh–Taylor experiments*
   k. *CEDrive-11A/ICEHohl-11A*
   l. *Strength diffraction*
2. *High-temperature plasma opacity*
   a. *High-temperature plasma opacity experiments on OMEGA and OMEGA EP*
3. *Hydrodynamics*
   a. *Short-pulse, UV backlighting development for the NIF*
   b. *Backlighting experiments on OMEGA*
4. *X-ray source development and application*
   a. *Iron K-shell x-ray source development*
   b. *Solar-cell electrostatic discharge*

4. FY11 LANL Omega Facility Programs

In FY11, LANL executed 223 total shots: 195 on the OMEGA Laser System and 28 on the OMEGA EP Laser System. LANL experiments contributed to the NIC in the following ways:

- *Measured the x-ray ablative Richtmyer–Meshkov growth of isolated defects on plastic ablators*
- *Studied branching ratios in DT-fusion plasmas*
- *Measured the shape of the DT-fusion gamma-ray spectrum*
- *Continued neutron-imaging development for the NIF*

HED campaigns included

- *Study of shear and reshock-driven turbulent mixing*
- *Backlit defect implosion experiments to study the effect of trench defect*
- *Measuring the effect of capsule asymmetries on neutron yield and ion temperature*
- *Platform development for dense plasmas and warm, dense matter's equation of state*
- *Measurement of a supersonic radiation wave*
- *Energetic ion generation for dynamic defect studies*

The LANL-led experiments are summarized beginning on p. 203.

5. FY11 AWE Omega Facility Experiments

In FY11, AWE led six shot days on the OMEGA and OMEGA EP lasers. This work encompassed the development of MeV x-ray sources (one day in jointly funded collaboration with CEA) and 22- to 52-keV x-ray backlighters (three days in collaboration with LLNL, of which one was LLNL funded), a Laue x-ray diffraction asymmetrically driven hohlraums (one day). The AWE work is reviewed beginning on p. 238.

6. FY11 CEA Omega Facility Experiments

CEA-led teams conducted 56 target shots on OMEGA during FY11. The experiments included vulnerability diagnostics development, neutron-imaging diagnostics development, implosion dynamics, and rugby hohlraum characterization. Summaries of some of the CEA work may be found beginning on p. 242.

FY11 Facility Report

During FY11, the Omega Laser Facility conducted 1348 target shots on OMEGA and 457 target shots on OMEGA EP for a total of 1805 target shots (see Tables 128.V and 128.VI) OMEGA averaged 10.3 target shots per operating day with availability and experimental effectiveness averages for FY11 of 93.3% and 96.1%, respectively. OMEGA EP was operated extensively in FY11 for a variety of internal and external users. Of the 457 target shots, 401 were shot in the OMEGA EP target chamber and 56 were joint shots in the OMEGA target chamber. OMEGA EP averaged 5.5 target shots per operating day with availability and experimental effectiveness averages for FY11 of 85.6% and 95.2%, respectively.

OMEGA EP Improved Energy Capabilities

Short-pulse (IR) and long-pulse (UV) energy on target has been increased. The UV energy was increased after the acquisition of improved optics. Lithographic-quality fused-silica substrates were finished using LLNL-developed protocols, LLNL-supported production controls, and the latest LLNL post-processing techniques for enhanced damage threshold (Acid Mitigation Process II). The extended UV energy operational envelope was made available after completion of a damage-testing laser shot campaign with the previous optics. UV energy on target was increased from 2.3 kJ per beam to 6.6 kJ at 10 ns, exceeding the 6.5-kJ system design goal. Short-pulse IR energy was increased following the installation of improved damage-threshold gratings in the grating-compressor vessel. Additionally, a comprehensive short-pulse small-beam damage-testing program was conducted on multilayer dielectric coatings. The combination of new gratings and coating performance analysis resulted in an increase to the IR energy operational envelope for the short-pulse laser beams. IR energy on target for beamline 2 at 10 ps was increased from 1.0 kJ to 1.6 kJ, 60% of the 2.6-kJ design goal. Up-to-date limits to the energy on target are now summarized and available to all users through the Operations Website.

OMEGA EP 100-ps UV Temporal Pulse Shapes

At the request of users, the shortest UV pulse durations have been extended from the previous limit of 1 ns to 100 ps. Users are now able to request pulse shapes between 100 ps and 10 ns. The 100-ps pulse shapes have been utilized to produce short-duration x-ray pulses useful for a variety of target-physics campaigns, including backlighter platform development for the NIF. With this new functionality, the temporal co-timing of all four beamlines has been calibrated to <50 ps.

OMEGA EP Short-Pulse Focal-Spot Improvement

Using a static wavefront corrector, wavefront correction has been developed for OMEGA EP to correct high-order residual wavefront that is beyond the spatial resolution of the existing adaptive optics. A small-aperture phase corrector, manufactured by QED Technologies, using the magnetorheological finishing (MRF) process, has been added to the injection system to precompensate for repeatable high-order wavefront errors that arise in the beamlines. Following successful proof-of-principle demonstrations, these optics were implemented on both of the OMEGA EP short-pulse beamlines, providing an ~2× reduction in focal-spot extent at the output of the beamline during active wavefront correction. On amplified shots, target-plane focal spots have met the specification of 80% of the energy in less than a 20-μm radius ($R_{80} < 20$ μm). An ~25% improvement is realized on the first shots, although thermal distortion of the amplifier disks has led to focal-spot degradation after multiple shots have been taken in a day. Future revisions of the phase-corrector design will partially compensate for this effect. This work follows on the successful implementation of advanced phase-retrieval techniques developed in FY10 that allow for accurate characterization of the focal spot.

OMEGA EP Infrared Alignment Table and Beamline Injection Table Enhancement

The daily operation of the OMEGA EP laser has been improved with enhancements to the OMEGA EP infrared alignment table (IRAT). This work improved the imaging accuracy from the laser source apodizer plane to the beamline input image plane. This improvement reduces modulation on critical optics in the OMEGA EP Laser System. Additional diagnostics were added to improve the injection energy measurements and centering of beams. All of these improvements have increased system operability.

Improved OMEGA UV On-Target Predictions

Target experiments have been shown to slowly degrade the UV transmission, primarily of the final debris shield, causing a decrease in on-target energy relative to the diagnostic prediction. During FY11, the study of UV transmission has resulted in a better understanding of the loss mechanisms. The study found that the losses are dependent on target type, target composition, target quantity, number of beams used for each shot, and beam location in the tank. The results of this study and daily measurements of transmission on representative UV optics have been incorporated into a new on-target energy prediction that is reported to the principal investigator. The system's average loss is predicted within ~1% accuracy and the rms error is <2%.

Experimental Diagnostics

Diagnostic capabilities continue to evolve with the commissioning of 24 new diagnostic instruments on OMEGA and 9 new diagnostic instruments on OMEGA EP. These include a new spherical crystal x-ray imager, upgraded hard x-ray diode arrays, *B*-dot magnetic-field probes, an electron spectrometer, and a new test platform for chemical vapor deposition-diamond neutron detectors. Many of these new instruments were developed by or in cooperation with other laboratories (including LLNL, LANL, CEA, Oxford University, Osaka University, and SNL). Improvements to the online information systems available to our scientific users include availability of specification sheets and operating procedures for diagnostic instruments, as well as target chamber port assignment tables. Other facility improvements include commissioning of an additional image plate scanner and electromagnetic interference hardening of the target positioners on both OMEGA and OMEGA EP.

A number of safety improvements were implemented in the experimental area. These include the commissioning of filtered air flow hoods for servicing equipment that contains or is contaminated with beryllium, higher-resolution beryllium-monitoring capability, and review and certification of heavy equipment lift procedures. Additionally, tracking beryllium survey data and radioactive material inventory has improved visibility to the operators and other stakeholders.

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. 166) to graduate education.

1. High School Student Program

During the summer of 2011, 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 systems and diagnostic development, computational modeling of implosion physics, chemistry, materials science, laser system development and diagnostics, and database development (see Table III).

The program culminated on 24 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 Website.

Two hundred and eighty-one high school students have now participated in the program since it began in 1989. Thirty of the participating students have gone on to gain semi-finalist status in the Intel Science Talent Search national competition and four of the students have gained finalist status at this competition.

At the symposium LLE presented its 15th annual William D. Ryan Inspirational Teacher Award to Mrs. Deborah Reynolds, chemistry teacher at Brighton 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.

Table III: High School Students and Projects—Summer 2011.

Name	High School	Supervisor	Project Title
Brandon Avila	Allendale Columbia	R. W. Kidder	Optimizing LLE Information Operations Through Natural Language Processing
Andrew Boyce	McQuaid	W. T. Shmayda	Water-Stimulated Tritium Release from Metals
Matthew DeCross	Pittsford Sutherland	L. D. Lund	Automation of Vibration Measurement and Characterization of Cryogenic Deuterium–Tritium Target Motion
Avery Gnolek	Webster Thomas	K. L. Marshall	Photoaligned Liquid Crystal Wave Plate
Dana Gretton	Honeoye Falls Lima	R. G. Peck, E. Druszkiewicz	Design of a New Master-Timing Generator
Sean Hamlin	Fairport	R. Epstein	X-Ray Fluorescence as an Imploded-Shell Diagnostic
Felix Jin	Brighton	G. Fiksel	Characterization of Magnetic Coils for the Magneto-inertial Fusion Energy Delivery System
Jefferson Lee	Canandaigua Academy	W. T. Shmayda	Modeling Tritium Removal from Metal Surfaces
Kevin Mizes	Pittsford Sutherland	R. Boni, D. H. Froula, S. Ivancic	Two Techniques for Array Generation with Applications in Grid-Imaging Refractometry
Patricia Olson	Brighton	R. S. Craxton	Optimization of Beam Configurations for Shock-Ignition Experiments on the NIF and OMEGA
Sean Reid	Fairport	M. Burke, R. Boni, S. D. Jacobs	Surface Grinding and Polishing to Remove Etch-Induced Noise Pitting in CR-39 Samples
Madeline Rutan	Penfield	K. L. Marshall	Abrasion-Resistant Antireflection Sol-Gel Coatings
Michael Statt	School of the Arts	K. L. Marshall, C. Dorrer	Generation of Radially Polarized Beams Using Optically Patterned Liquid Crystals
Troy Thomas	Webster Thomas	B. E. Kruschwitz	Optical Time-Domain Reflectometry for the Transport Spatial Filter on the OMEGA Extended Performance Laser
Harrison Xiao	Pittsford Sutherland	P. A. Jaanimagi	Dynamic Defocusing in Streak Tubes
Andrew Zhao	Webster Thomas	R. Boni, D. H. Froula, S. Ivancic	Image Processing and Analysis of 4ω Grid-Image Refractometry Data

Teachers are nominated by alumni of the summer program. Mrs. Reynolds was nominated by Nicholas Andrew Chun and Connie Chiang, participants in the 2010 Summer Program.

2. Undergraduate Student Programs

Approximately 41 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 HED 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, 77 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, HED 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 President, University of Rochester