Executive Summary

The fiscal year ending September 2008 (FY2008) concluded the first 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. It also reports on LLE's progress on laser, optical materials, and advanced technology development; the completion of the OMEGA EP High-Energy, Petawatt-Class Laser System on time and on budget; operation of OMEGA for 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

The research program at the University of Rochester's Laboratory for Laser Energetics (LLE) focuses on inertial confinement fusion (ICF) research supporting the goal of achieving ignition on the National Ignition Facility (NIF). This program includes the full use of the OMEGA EP Laser System. Within the National Ignition Campaign (NIC), LLE is the lead laboratory for the validation of the performance of cryogenic target implosions, essential to all forms of ICF ignition. LLE has taken responsibility 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 is also developing, testing, and building a number of diagnostics to be deployed on the NIF for the NIC.

During this past year, progress in the inertial fusion research program was made in three principal areas: NIC experiments; development of diagnostics for experiments on OMEGA, OMEGA EP, and the National Ignition Facility (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 FY08, LLE, in collaboration with the Plasma Science Fusion Center–MIT, RSI Corporation, Naval Research Laboratory (NRL), and the Nuclear Research Center Negev, continued investigations of ignition-scaled cryogenic capsule implosions. Successful ignition target designs depend on two important issues: the ability to maintain the fuel adiabat at a low level and the control of nonuniformity growth during the implosion. A series of experiments were carried out on OMEGA (p. 16) to study the physics of low-adiabat, high-compression cryogenic capsule assembly. High-areal-density (with $\rho R > 0.2$ g/cm^2) cryogenic-fuel assembly is reported on OMEGA designs where the shock timing was optimized using the nonlocal treatment of the heat conduction and the suprathermal electron preheat by the two-plasmon-decay instability was mitigated.

The current status and future development of LLE's work on layering cryogenic D_2 and DT targets are presented in a report on p. 57. This essential effort achieved the milestone of routinely providing cryogenic DT capsules that meet the 1.0-μm (rms) OMEGA ice-surface-quality specification. The best D_2 layers achieved so far (rms roughness of 1.1 μm) are approaching the quality achieved in DT targets. Efforts to improve the consistency of this process are reported along with investigations that support the National Ignition Campaign's study of issues relevant to ignition-scale indirect-drive and direct-drive cryogenic targets.

The results of a collaborative project (including LLE, LLNL, and the University of California, Davis) on suprathermal electron production in gas-filled hohlraums are reported beginning on p. 139. Two bursts of high-energy electrons are observed when such hohlraums are driven with 13.5 kJ of 351-nm light on OMEGA. The two-plasmon-decay (TPD) instability in the exploding laser-entrance-hole (LEH) window appears to produce up to 20 J of hot electrons with $T_{hot} \sim 75$ keV at very early times and a very sharp laser-intensity threshold at $\sim 0.5 \times 10^{15}$ W/cm^2. The second pulse, produced by stimulated

Raman scattering (SRS) during the main laser drive, has more energy (~200 J) but significantly lower T_{hot} ~ 20 keV. This was the first such observation of the TPD instability in a hohlraum-configuration target.

Studies of energy transfer from high-intensity laser pulses into solid-density targets address basic issues in laser–plasma interactions, including electron acceleration, ion acceleration, and secondary radiation generation. In this volume (p. 1) we report on target experiments using LLE's Multi-Terawatt (MTW) Laser Facility to study isochoric heating of solid-density targets by fast electrons produced from intense, short-pulse laser irradiation. Electron refluxing occurs due to the target-sheath field effects and contains most of the fast electrons within the target volume. This process can efficiently heat the solid-density plasma through collisions. X-ray spectroscopic measurements of the absolute K_α photon yields and variations of the K_α/K_β emission ratio both indicate that laser energy couples to fast electrons with a conversion efficiency of ~20%. Bulk electron temperatures of at least 200 eV are inferred for the smallest-mass targets.

A collaborative team including LLE, Plasma Science and Fusion Center–MIT, LLNL, RAL, and GA reports on a comprehensive program underway at LLE to explore the physics of fast ignition (p. 120). The OMEGA EP Laser Facility, completed in April 2008, is located adjacent to the 60-beam, 30-kJ OMEGA Laser Facility and consists of four beamlines with a NIF-like architecture. Two of the beamlines can operate as high-energy petawatt (HEPW) lasers, with up to 2.6 kJ each with 10-ps pulse duration. These beams can be either injected into the OMEGA EP target chamber or combined collinearly into the existing OMEGA target chamber for integrated fast-ignitor experiments. Fuel-assembly experiments on OMEGA have achieved high fuel areal densities, and the effects of a cone on the fuel assembly are being studied. Experiments on short-pulse laser systems in collaboration with other institutions are being pursued to investigate the conversion efficiency from laser energy to fast electrons. A coherent transition radiation diagnostic is being developed to study the transport of the electrons in high-density material. Integrated experiments with room-temperature targets were performed in 2008 on OMEGA. Simulations of these integrated experiments show significant heating of up to 1 keV due to the hot electrons from the short-pulse laser.

Measurements of time-resolved absorption in cryogenic and room-temperature, direct-drive implosions on OMEGA are reported on p. 36. Time-dependent and time-integrated absorption fractions are inferred from scattered-light measurements that agree reasonably well with hydrodynamic simulations that include nonlocal electron-heat transport. Discrepancies in the time-resolved scattered-light spectra between simulations and experiments remain for complex laser pulse shapes, indicating beam-to-beam energy transfer and commensurate coupling losses. Time-resolved scattered-light spectra near $\omega/2$ and $3\omega/2$, as well as time-resolved hard x-ray measurements, indicate the presence of a strongly driven TPD instability at high intensities that may influence the observed laser light absorption. Experiments indicate that energetic electron production due to the TPD instability can be mitigated with high-Z-doped plastic shells.

A collaborative team comprised of scientists from LLE, LLNL, Plasma Science and Fusion Center–MIT, and Nuclear Research Center Negev presents initial results from experiments on the shock-ignition inertial confinement fusion concept (p. 25). Shock ignition is a two-step inertial confinement fusion concept where a strong shock wave is launched at the end of the laser pulse to ignite the compressed core of a low-velocity implosion. Initial shock-ignition technique experiments used 40-μm-thick, 0.9-mm-diam, warm surrogate plastic shells filled with deuterium gas. These experiments showed a significant improvement in the performance of low-adiabat, low-velocity implosions compared to conventional "hot-spot" implosions. High areal densities with average values exceeding ~0.2 g/cm^2 and peak areal densities above 0.3 g/cm^2 were measured, in good agreement with one-dimensional hydrodynamic simulation predictions. Shock-ignition-technique implosions with cryogenic deuterium and deuterium–tritium ice shells also produced areal densities close to the 1-D prediction and achieved up to 12% of the predicted 1-D fusion yield.

A physical understanding of heating generated by shock waves, radiation, and energetic electrons is required to effectively control the pressure in the main fuel layer of direct-drive capsules. On p. 185, we report on studies of shock-wave–heated and compressed planar targets using time-resolved Al 1s–2p absorption spectroscopy as a diagnostic. Significant discrepancies between the measured and predicted shock-wave heating were observed at late times in the drive, which can be explained by reduced radiative heating due to lateral heat flow in the coronal plasma.

We report on the effectiveness of a laser shinethrough barrier for direct illumination of a spherical target in direct-drive inertial confinement fusion experiments (p. 144). In the earliest stages of irradiation, before the plasma forms a critical-density surface, laser light can penetrate into the target. This "shinethrough" light can be sufficiently intense to undergo filamentation and to damage the inside of the target, thereby seeding hydrodynamic instabilities. Laser shinethough can be blocked by a thin coating of opaque material such as aluminum (Al). For cryogenic direct-drive targets, the shinethrough barrier material must also be compatible with cryogenic target fabrication procedures, which rules out Al layers since they would interfere with the permeation filling and optical characterization of cryogenic targets. Silicon (Si) has been found to be a promising candidate for a direct-drive cryogenic target shinethrough barrier material. Several cryogenic targets have been coated with Si, successfully permeation filled with either D_2 or DT, and subsequently layered and optically characterized. Various thicknesses of Si coatings have been applied to planar targets and tested under relevant irradiation conditions. Experiments have shown that 200 μm of Si is sufficient to protect targets from laser shinethrough.

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

In collaboration with LLNL and SNL, LLE achieved an important diagnostic milestone in FY08 by validating a technique to measure multi-shock timing on the NIF. Shock timing is performed with optical diagnostics (VISAR and ASBO) using the experimental configuration illustrated in Fig. 1. For this measurement, the target is placed at the end of a cone inserted inside a NIF-scale hohlraum that reaches radiation temperatures of ~165 eV. The capsule and cone are filled with liquid deuterium, and an external window enables the optical diagnostics to view the internal surface of the capsule along the axis of the cone. This measurement was highlighted in an invited paper delivered at the 50th Annual Meeting of the American Physical Society Division of Plasma Physics in November 2008.

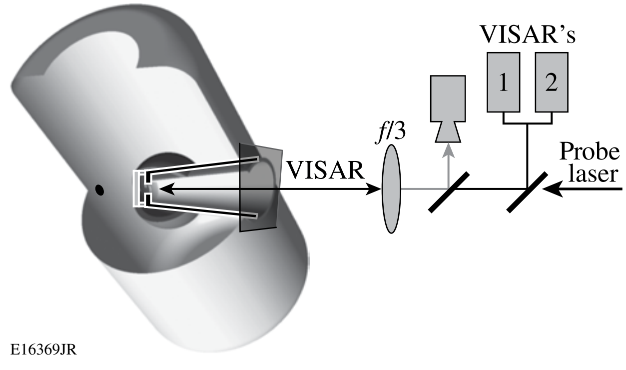

Figure 1
Schematic of experimental configuration for multi-shock timing experiments on hohlraum-driven cryogenic D_2 targets.

A collaborative effort by the Plasma Science and Fusion Center–MIT and LLE on monoenergetic proton radiography of field and density distributions in inertial confinement fusion implosions is reported on p. 47. This unique imaging technique reveals field structures through deflection of proton trajectories, and areal densities are quantified through energy lost by protons while traversing the plasma. Two distinctly different types of electromagnetic-field configurations are observed during implosions, and the capsule size and areal-density temporal evolution are measured. The first field structure consists of many radial filaments with complex striations and bifurcations that permeate the entire field of view with 60-T magnetic field magnitudes, while another coherent, centrally directed electric field of the order of 10^9 V/m is seen near the capsule surface. Although the mechanisms for generating these fields are not yet fully understood, their effect on implosion dynamics is expected to be consequential.

In related work, a collaborative team including the Plasma Science and Fusion Center–MIT, LLE, Nuclear Research Center Negev, LLNL, and General Atomics reports on time-gated, monoenergetic proton radiography that provides unique measurements of implosion dynamics of spherical targets in direct-drive inertial confinement fusion (ICF) (p. 81). Radiographs obtained at different implosion times, from acceleration through coasting and deceleration to final stagnation, display a comprehensive picture of a spherical ICF implosion. Critical information inferred from such images characterizes the spatial structure and temporal evolution of self-generated fields and plasma areal density.

Scientists from LLE and the University of Rochester's Institute of Optics report on the design of a high-resolution optical transition radiation diagnostic for fast-electron-transport studies on the MTW Laser Facility (p. 9). Coherent transition radiation is generated as relativistic electrons, generated in high-intensity laser–plasma interactions, exit the target's rear surface and move into vacuum. High-resolution images of the rear-surface optical emission from high-intensity ($I \sim 10^{19}$ W/cm^2) laser-illuminated metal foils have been recorded using a transition radiation diagnostic (TRD). The detector is a scientific-grade charge-coupled-device (CCD) camera that operates with a signal-to-noise ratio of 10^3 and a dynamic range of 10^4. The TRD has demonstrated a spatial resolution of 1.4 nm over a 1-mm field of view, limited only by the CCD pixel size.

3. Theoretical Analysis and Design

A systematic investigation of the effect of low-ℓ-mode perturbations on neutron-yield degradation of direct-drive, low-adiabat (α ~ 2 to 3) cryogenic D_2 implosions is reported (p. 172). This study uses 2-D *DRACO* simulations to show that for thin-shell targets (~5 μm), the yield degradation can be explained by the combined perturbations for the target offset, the low-ℓ-mode ice roughness, and the low-ℓ-mode laser illumination nonuniformities. For similar pulse shapes, thick-shell targets generally do not perform as well as thinner-shell targets. This indicates that high-ℓ-mode perturbations such as laser imprinting may play a role in further reducing neutron yields in thick-shell targets.

We report (p. 204) on theoretical work to develop an accurate representation of measurable Lawson criterion for inertial fusion with DT fuel. This ignition condition is found using an analytical dynamic model of ignition, and it is confirmed by the results of one-dimensional simulations of marginally ignited direct-drive targets (gain ~ 1). A simple fit of the ignition condition can be written as $\left\langle T_i^{\text{no}\,\alpha}\right\rangle_{\text{n}}^{2.6} \times \left\langle \rho R_{\text{tot}}\right\rangle_{\text{n}} > 50\ \text{keV}^{2.6} \times \text{g}/\text{cm}^2$. This ignition condition is given in terms of only two measurable parameters of the fuel: (1) the burn-averaged total areal density $\langle \rho R_{\text{tot}} \rangle_{\text{n}}$ and (2) the neutron-averaged hot-spot ion temperature $\langle T_i^{\text{ no}\,\alpha} \rangle_{\text{n}}$ without accounting for the α-particle deposition.

The creation of relativistic, hot electron–positron plasma in the laboratory is an ambitious experimental challenge that has yet to be realized. Electron–positron pair plasmas are theoretically interesting because of the mass symmetry between plasma components. Electron–positron plasmas are important in astrophysical settings, and there have been proposals to use electron–positron plasmas as energy sources for space propulsion. We report on theoretical calculations (p. 161) of the expected electron–positron pair production that may be attained on future experiments on OMEGA EP. It is shown that a yield of ~5 $\times$ 10^{11} pairs may be possible on OMEGA EP provided that the hot-electron temperature is consistent with the ponderomotive scaling.

Lasers, Optical Materials, and Advanced Technology

An improved laser speckle smoothing scheme is reported (p. 73) that augments the current NIF 1-D SSD system by using multiple-FM modulators (MultiFM 1-D SSD). With a judicious choice of modulator frequencies, MultiFM 1-D SSD smoothes resonances that are produced at the higher spatial frequencies and can attain similar or even faster smoothing rates compared to the baseline NIF 2-D SSD system. *DRACO* simulations have shown that MultiFM 1-D SSD beam smoothing is sufficient for the direct-drive-ignition targets and pulse shapes analyzed thus far and may even make it possible to reduce the bandwidth enough to eliminate the need for dual-crystal frequency conversion on the NIF.

A single-shot cross-correlator based on a pulse replicator that produces a discrete sequence of sampling pulses that are nonlinearly mixed with the pulse under test is discussed (p. 86). The combination of a high reflector and partial reflector replicates an optical pulse by multiple internal reflections and generates a sequence of spatially displaced and temporally delayed sampling pulses. This principle is used in a cross-correlator characterizing optical pulses at 1053 nm, where a dynamic range higher than 60 dB is obtained over a temporal range larger than 200 ps. The dynamic range can be extended with standard optical-density filters and the temporal range extended with larger optics.

A novel focal-spot diagnostic developed for OMEGA EP will be used to characterize on-shot focal spots to support high-quality laser–matter interaction experiments (p. 94). The complex fields in the region of the high-energy focus are calculated using high-resolution measurements of the main beam wavefront using the focal-spot diagnostic (FSD) located on the short-pulse diagnostic package and a careful calibration of the transfer wavefront between the FSD instrument and target chamber center. The concept of this calibration procedure is experimentally verified in the Multi-Terawatt (MTW) Laser System, which serves as a development platform for OMEGA EP. A technique based on phase retrieval is employed for the transfer-wavefront calibration since the OMEGA EP infrastructure cannot be replicated in the MTW laser; however, this approach also shows promise as an alternative method for OMEGA EP.

A systematic study has been conducted to improve the laser-damage resistance of multilayer high-reflector coatings for use at 351 nm on the OMEGA EP Laser System (p. 103). A series of hafnium-dioxide monolayer films deposited by electron-beam evaporation with varying deposition rates and oxygen backfill pressures were studied using transmission electron microscopy (TEM), x-ray diffraction (XRD), and refractive-index modeling. These coatings exhibit microstructural changes for sufficiently slow deposition rates and high oxygen backfill pressures, resulting in an absence of crystalline inclusions and a lower refractive index. This process was used to fabricate reduced-electric-field–type multilayer, high-reflector coatings that achieved laser-damage thresholds as high as 16.6 J/cm^2, which represents exceptional improvement over previous damage thresholds measured at this wavelength of the order of 3 to 5 J/cm^2.

Two large-aperture (1.5-m) tiled-grating compressors—each consisting of four sets of tiled-grating assemblies—have been built and successfully implemented on the OMEGA EP laser (p. 113). The techniques used for tiling individual tiled-grating assemblies and for optimizing the overall performance of a tiled-grating compressor are described. Both compressors achieved subpicosecond-pulse duration without tiling-induced temporal degradation. A ray-tracing model predicted that the static wavefront of the grating tiles dominate focal-spot degradations when submicroradian tiling accuracy is achieved. The tiled-grating compressors delivered a tighter focal spot compared to sub-aperture grating compressors with single central tiles.

An on-shot focal-spot diagnostic is presented for characterizing high-energy, petawatt-class laser systems (p. 130). Accurate measurements at full energy are demonstrated using high-resolution wavefront sensing in combination with techniques to calibrate on-shot measurements with low-energy sample beams. Results are shown for full-energy activation shots on OMEGA EP.

The suppression and elimination of self-pulsing in a watt-level, dual-clad, ytterbium-doped fiber laser are reported (p. 150). Self-pulsations are caused by the dynamic interaction between the photon population and the population inversion. The addition of a long section of passive fiber in the laser cavity makes the gain recovery faster than the self-pulsation dynamics, allowing only stable continuous-wave lasing. This scheme provides a simple and practical method for eliminating self-pulsations in fiber lasers at all pumping levels.

A collaborative team from LLE and the Kavli Institute of Nanoscience, Delft University of Technology reports on a new readout scheme for NbN superconducting single-photon detectors (SSPD's), using a low-noise, cryogenic high-electron mobility transistor and a high-load resistor directly integrated with the detector to achieve amplitude resolution of dark and photon counts (p. 153). This scheme makes it possible to study the physical origin of dark counts in SSPD's and may enable both photon-number-resolving and energy-resolving capabilities of the standard, meander-type SSPD.

Superconductivity is still regarded as a very promising technology to be applied to high-performance electronics (e.g., Josephson junction digital circuits, ultrasensitive magnetometers) and optoelectronics (e.g., broadband x-ray to visible-light photoconductors, optical single-photon and photon-counting detectors). A comprehensive study of the time-resolved dynamics of Cooper pairs and quasiparticles in Hg-based superconductors begins on p. 219.

OMEGA Extended Performance (OMEGA EP)

The OMEGA EP project was completed in April 2008—on time and on budget. The formal Critical Decision 4 (CD-4) milestone was approved by the NNSA Acquisition Executive on 6 May 2008. OMEGA EP accomplished all project completion criteria, demonstrating short- and long-pulse capability. In total there were over 3000 test shots on OMEGA EP during the period from August 2006 to 30 April 2008. Highlights of the activation and CD-4 demonstration shots included Beams 1 and 2 being successfully operated to the OMEGA EP and OMEGA target chambers. Beam 1 achieved 600 J of infrared (IR) short-pulse energy (400 J required) at <100-ps duration, and Beam 2 achieved 424 J of IR short-pulse energy (400 J required) at ~10 ps. All four beams were operated at >1-kJ ultraviolet (UV) in long-pulse operational mode. During the week of 31 March 2008, the OMEGA EP laser fired 22 shots into the OMEGA target chamber. A CD-4 Project Completion review was conducted on-site by NNSA on 23–24 April to validate project completion. The system performance requirements were met with two minor exceptions (described below) and the facility transitioned to operations in May 2008.

The project completion criteria were established in a formal Project Completion and Certification Plan. Project completion was based on compliance with all sections of this plan. All appropriate project documentation was made available for review by NNSA to verify that applicable requirements of DOE Order 413.3A *Program and Project Management for the Acquisition of Capital Assets* for project completion and start of operations had been satisfied. The top-level system technical and functional performance requirements for the project were specified at the start of the project. The performance characteristics for each beamline were divided between the short- and long-pulse beam characteristics. These criteria were as follows:

<u>Short-pulse beams</u>

Beamlines 1 and 2 activated for high-intensity experiments with a joint OMEGA target shot to include the following conditions:

- Beamline 1 having a pulse width of ≤100 ps, Beamline 2 a pulse width of ≤10 ps

- Beamline 2 timed with respect to Beamline 1 to the desired delay with an uncertainty of less than 10-ps rms
- OMEGA EP beams timed to the OMEGA beams to the desired delay with an uncertainty of less than 20-ps rms
- Each beam having an on-target energy of ≥400 J
- Focal-spot conditions where >80% of the on-target energy will be within a 40-μm-diam spot
- Irradiation of a backlighter foil in OMEGA using Beamline 1 or 2 to include the criteria above and repeated within 2 h

<u>Long-pulse beams</u>

All four beamlines activated for the single-sided irradiation of a foil target in the auxiliary target chamber to include the following conditions:

- Pulse durations between 1 to 10 ns for each beam, configurable
- On-target total energy ≥1000 J per beam at 351 nm, at 2 ns or longer
- All four beamlines co-timed to less than 40-ps rms
- Focal-spot conditions where >95% of the UV energy is contained in a 1-mm-diam spot

These system performance criteria were deemed to have been met with two exceptions, neither of which precluded OMEGA EP from satisfying the primary functional requirements defined in the Statement of Mission Need. The first exception was that the OMEGA EP short-pulse suite of diagnostics includes a new and novel method for measuring the focal-spot size on target. This instrument, the Focal-Spot Diagnostic, acquired high-quality data on its initial use. The focal-spot size during the CD-4 shot campaign to OMEGA was measured on one beam to be 30- to 35-μm radius (radius that contains 80% of the energy, R_{80}), whereas the requirement is $R_{80} < 20\ \mu$m. The other short-pulse beam focal spot was not measured. Subsequent to project completion the focal spots of both beams were improved and are, as of the end of FY08, very near the R_{80} requirement. The second exception was that Beamlines 1 and 2 were not shot on target in long-pulse mode due to the unavailability of UV focus lenses. The beamlines were, however, shot at >1000-J-equivalent on-target energy with the beam terminated at the UV diagnostics. The UV focus lenses were awaiting conditioning, initiation, and mitigation (CIM) at LLNL to achieve high UV laser damage fluence. In order not to impact the National Ignition Facility schedule, a programmatic decision was made to wait until LLNL could reasonably process the optics and deliver them to LLE.

National Laser Users' Facility (NLUF) and External Users' Programs

During FY08, a governance plan was implemented to formalize the scheduling of the OMEGA Laser Facility as an NNSA User Facility. Under this plan, OMEGA shots are allocated by campaign. The majority of the FY08 target shots were allocated to the National Ignition Campaign (NIC), and integrated experimental teams from LLNL, LANL, SNL, and LLE conducted a variety of NIC-related experiments primarily at the OMEGA facility. Shots were also allocated in FY08 to the high-energy-density (HED) physics programs from LLNL and LANL.

Under the governance plan 25% of the facility shots are allocated to Basic Science experiments. Roughly half of these are dedicated to University Basic Science under the National Laser Users' Facility Program and the remaining shots are allotted to Laboratory Basic Science, comprising peer-reviewed basic science experiments conducted by the national laboratories and LLE/FSC.

In total, nearly 49% of the OMEGA shots in FY08 were dedicated to external users including the NLUF programs, LLNL, LANL, SNL, CEA (France), and AWE (UK, Atomic Weapons Establishment).

1. NLUF Experiments

In FY08, the Department of Energy (DOE) issued a solicitation for NLUF grants for the period of FY09–FY10. A total of 13 proposals were submitted to DOE for the NLUF FY09–FY10 program. An independent DOE Technical Evaluation Panel reviewed the proposals and recommended that 11 of the proposals receive DOE funding and shot time on OMEGA in FY09–FY10. Table I lists the successful proposals.

Fiscal year 2008 was the second year of a two-year period of performance for the NLUF projects approved for FY07–FY08 funding and OMEGA shots. A total of 125 shots were conducted for six NLUF projects. The progress of some this work is detailed beginning on p. 228 in the following reports:

- *Experimental Astrophysics on the OMEGA Laser*
  (R. P. Drake, University of Michigan)

- *Laboratory Experiments on Supersonic Astrophysical Flows Interacting with Clumpy Environments*
  (P. Hartigan, Rice University)

- *Multiview Tomographic Study of OMEGA Direct-Drive-Implosion Experiments*
  (R. Mancini, University of Nevada, Reno)

- *Monoenergetic Proton Radiography of ICF Implosions*
  (R. D. Petrasso and C. K. Li, Massachusetts Institute of Technology)

- *X-Ray Thompson-Scattering Spectra in Shock-Compressed Beryllium*
  (R. Falcone and H. J. Lee, University of California at Berkeley)

2. FY08 LLNL OMEGA Experimental Programs

In FY08, Lawrence Livermore National Laboratory (LLNL) led 238 target shots on the OMEGA Laser System. Approximately half of these experiments were dedicated to the National Ignition Campaign (NIC); the other half were dedicated to supporting the high-energy-density stewardship experiments (HEDSE's).

Objectives of the LLNL-led NIC campaigns on OMEGA included the following:

- *Laser–plasma interaction studies of physical conditions relevant for the National Ignition Facility (NIF) ignition targets*

- *Studies of the x-ray flux originating from the laser entrance hole (LEH) window of a hohlraum, which might impact the performance of a fusion capsule*

- *Characterization of the properties of warm dense matter—specifically radiatively heated Be*

Table I: Approved NLUF proposals for FY09–FY10.

Principal Investigator	Institution	Project Title
Farhat Beg	University of California, San Diego	Systematic Study of Fast Electron Transport and Magnetic Collimation in Hot Plasmas
Paul Drake	University of Michigan	Experimental Astrophysics on the OMEGA Laser
Roger Falcone	University of California, Berkeley	Detailed *In-Situ* Diagnostics of Multiple Shocks
Uri Feldman	ARTEP, Inc.	EP-Generated X-Ray Source for High-Resolution 100–200 keV Point Projection Radiography
Yogendra Gupta	Washington State University	Ramp Compression Experiments for Measuring Structural Phase Transformation Kinetics on OMEGA
Patrick Hartigan	Rice University	Dynamics of Shock Waves in Clumpy Media
Raymond Jeanloz	University of California, Berkeley	Recreating Planetary Core Conditions on OMEGA, Techniques to Produce Dense States of Matter
Karl Krushelnick	University of Michigan	Intense Laser Interactions with Low Density Plasmas Using OMEGA EP
Roberto Mancini	University of Nevada, Reno	Three-Dimensional Studies of Low-Adiabat Direct-Drive Implosions at OMEGA
Mark Meyers	University of California, San Diego	Response of BCC Metals to Ultrahigh Strain Rate Compression
Richard Petrasso	Massachusetts Institute of Technology	Monoenergetic Proton and Alpha Radiography of Laser-Plasma-Generated Fields and ICF Implosions

- *Studies of the physical properties of capsules based on Cu-doped Be, high-density carbon, and conventional plastics, including new high-resolution shock-velocimetry measurements*
- *Determining ablator performance during the implosion of NIC-candidate ablators*
- *Experiments to study the physical properties (thermal conductivity) of shocked fusion fuels*
- *High-resolution measurements of velocity nonuniformities created by microscopic perturbations in NIF ablator materials*
- *Demonstration of T_r = 100-eV foot-symmetry tuning using a re-emission sphere*
- *Demonstration of T_r = 100-eV foot-symmetry tuning using a backlit thin-shell capsule*
- *Quantification of x-ray foot preheat caused by laser–window interaction*

The LLNL HEDSE campaigns included the following:

- *Quasi-isentropic [isentropic compression experiment (ICE)] drive used to study material properties such as strength, equation of state, phase, and phase-transition kinetics under high pressure*
- *Development of long-duration, point-apertured, point-projection x-ray backlighters*
- *Development of an experimental platform to study nonlocal thermodynamic equilibrium (NLTE) physics using direct-drive implosions*
- *Opacity studies of high-temperature plasmas under LTE conditions*
- *Development of multikilovolt x-ray sources using underdense NLTE plasmas for x-ray source applications*
- *Studies of improved hohlraum heating efficiency using cylindrical hohlraums with foam walls*
- *Laser-driven dynamic-hohlraum (LDDH)-implosion experiments*
- *High-speed hydrodynamic jets for code validation*

3. FY08 LANL OMEGA Experimental Programs

Los Alamos National Laboratory (LANL) successfully fielded a range of experiments on the OMEGA laser during FY08 studying the physics relevant to inertial confinement fusion (ICF) and high-energy-density laboratory plasma (HEDLP) in support of the national program. LANL conducted a total of 85 target shots on OMEGA. Collaborations with LLNL, LLE, MIT, and AWE remain an important component of LANL's program on OMEGA.

As reported beginning on p. 248, the LANL-led campaign included the following experiments:

- *AGEX-EOS experiments aimed at exploring radiative preheating in Richtmyer–Meshkov (RM) mix of large-Atwood-number interfaces*
- *"DT ratio–^{3}He" experiment to investigate the effect of helium on yield and reaction history of DT implosions*
- *The "Hi-Z" experiment to study the effects of instability growth and the resulting mix*
- *NIF Platform #5—aimed at developing x-ray diagnostic techniques to measure temperature in future NIF radiation transport experiments*
- *The "symergy" experiment to test the concept of using thin shells to quantify asymmetry during the foot of an NIF ignition drive pulse*

4. FY08 CEA OMEGA Experimental Programs

During FY08, CEA scientists led 39 target shots on OMEGA—four more than the nominal allocation. Reports on the experiments begin on p. 253 and include the following:

- *Development and testing of data acquisition systems that can operate under harsh radiation environments*
- *Exploration of monocrystaline diamond CVD detectors for time-resolved neutron measurements*
- *Development of neutron imaging on OMEGA*

5. FY08 AWE OMEGA Experimental Programs

AWE scientists conducted 32 OMEGA target shots in FY08—two more than the nominal allocation. The experiments focused on studies of radiation transport and hohlraum symmetry.

FY08 Laser Facility Report

The OMEGA facility conducted 1169 target shots on OMEGA and 85 target shots on OMEGA EP for a variety of users in FY08 (see Table II). The OMEGA Availability and Experimental Effectiveness averages for the year were 91.3% and 96.1%, respectively. Highlights of the year included the following:

- *Pulse-shaping capability was enhanced to include double and triple picket pulses for cryogenic experiments on OMEGA.*
- *The picket-generation hardware has been upgraded to allow for the creation of independent timing/amplitude control of the pickets.*
- *A new harmonic energy detector (HED) system was designed and implemented to replace the legacy system on OMEGA.*
- *The Fiducial Laser System was upgraded to solid-state, diode-pumped regenerative amplifier technology.*
- *All rod amplifier power conditioning unit control systems were upgraded with improved trigger boards.*
- *A new Target Viewing System (TVS) was installed on the OMEGA target chamber. The new system features real-time image processing, up to a 50-mm field of view, up to 2000-frames/s data collection, cryogenic target imaging improvements, remote focus capability, and target detection improvements.*
- *New environmental controls were added to the Pulse-Generation Room (PGR).*
- *The OMEGA EP Laser Facility completed the integration to target of two short-pulse beamlines and two long-pulse UV beamlines.*
- *Two additional ten-inch manipulators (TIM's) were commissioned for the OMEGA EP chamber, bringing the total to three.*
- *A suite of new target diagnostics were qualified for OMEGA EP.*
- *A NIF preamplifier module (PAM) was installed in the OMEGA EP Laser Sources Bay.*

Education at LLE

As the only major university participant in the National ICF Program, education continues to be an important mission for the Laboratory. A report on this year's Summer High School Research Program is described in detail on p. 224. Fourteen students participated in this year's program. The William D. Ryan Inspirational Teacher Award was presented to Ms. Jane M. Bowdler, an Advanced Placement (AP) calculus and pre-calculus teacher at Brockport High School.

Table II: The OMEGA target shot summary for FY08.

Laboratory	Planned Number of Target Shots	Actual Number of Target Shots	IDI NIC	DDI NIC	Total NIC	Non NIC
LLE	607	600	145	409	554	46
LLNL	221	237	117	0	117	120
NLUF	114	125	0	0	0	125
LANL	85	85	22	0	22	63
LBS	50	51	0	0	0	51
CEA	35	39	0	0	0	39
AWE	30	32	0	0	0	32
Total	1142	1169	284	409	693	476

Graduate students are using the OMEGA laser for fusion research and other facilities for HED research and technology development. They are making significant contributions to LLE's research activities. Twenty-five faculty from five departments collaborate with LLE's scientists and engineers. Presently, 87 graduate students are involved in research projects at LLE, and LLE directly sponsors 39 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 fabrications technology, and target fabrication.

Approximately 66 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 Plasma Science and Fusion Center–MIT, the State University of New York (SUNY) at Geneseo, the University of Nevada, Reno, and the University of Wisconsin. These programs involve a total of approximately 16 graduate students, 27 undergraduate students, and 7 faculty members.

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