Executive Summary

The federal fiscal year ending September 2017 (FY17) concluded the first 54 months of the fourth five-year renewal of Cooperative Agreement DE-NA0001944 with the U.S. Department of Energy (DOE). This annual report summarizes work carried out under the Cooperative Agreement at the Laboratory for Laser Energetics (LLE) during the past fiscal year including work on the Inertial Confinement Fusion (ICF) Campaign; laser, optical materials, and advanced technology development; operation of the Omega Laser Facility for the ICF and High-Energy-Density (HED) Campaigns, the National Laser Users' Facility (NLUF), the Laboratory Basic Science (LBS) Program, and other external users; and programs focusing on the education of high school, undergraduate, and graduate students during the year.

Inertial Confinement Fusion Research

One of LLE's principal missions is to conduct research in ICF with particular emphasis on supporting the goal of achieving ignition at the National Ignition Facility (NIF). This program uses the Omega Laser and NIF facilities and the full experimental, theoretical, and engineering resources of the Laboratory. During FY17, 2138 target shots were taken at the Omega Laser Facility (comprised of the 60-beam OMEGA UV laser and the four-beam, high-energy petawatt OMEGA EP laser). Of the facility's 2138 target shots, 72% were designated for ICF and HED campaigns. LLE is the lead laboratory worldwide for the laser-direct-drive approach with research focused on cryogenic implosions on the 60-beam OMEGA laser. LLE is responsible for a number of critical elements within the Integrated Experimental Teams that support the demonstration of indirect-drive ignition on the NIF and is the lead laboratory for the validation of direct-drive ignition. LLE has also developed, tested, and constructed a number of diagnostics currently being used at both the Omega Laser Facility and on the NIF. During this past year, progress in the Inertial Fusion Research Program continued in three principal areas: ICF experiments and experiments in support of ICF; theoretical analysis and design efforts aimed at improving direct-drive–ignition capsule designs and advanced ignition concepts; and development of diagnostics for experiments on the NIF, OMEGA, and OMEGA EP facilities.

1. Inertial Confinement Fusion Experimental Highlights in FY17

Measurements of the deuterium–tritium (DT) to deuterium–deuterium (DD) fusion neutron yield ratio were used (p. 23) to evaluate species separation in OMEGA cryogenic target implosion experiments. No species separation was found in these experiments.

Beginning on p. 29 we report on OMEGA spherically converging shock experiments, comparing CH, Be, C, and SiO_2 ablators. CH gives 2 to 3× more hot electrons than other ablators and, as expected, a higher effective ablation pressure.

OMEGA cryogenic target experiments are presented (p. 36) in which x-ray self-emission diagnostics were deployed using the short-pulse OMEGA EP laser to drive a Si He_α x-ray backlighter. The evolution of nonuniform ablators, perturbations caused by mounting stalks, and carbon mix into the DT are observed for capsule adiabats lower than 4.

An overview of the development of a laser-driven MagLIF (magnetized liner inertial fusion) platform on the OMEGA laser is provided (p. 10). MagLIF was developed at the Z Pulsed Power Facility at Sandia National Laboratories and is a key target concept in the U.S. ICF Program. Laser-driven MagLIF on OMEGA is being developed to provide the data on energy scaling and to allow for more shots with better diagnostic access than Z, including proton radiography, to more directly measure embedded B fields, facilitating basic physics studies.

The mitigation of cross-beam energy transfer (CBET) in OMEGA direct-drive implosions by wavelength detuning the three separate legs of the system using a 3-D model is being investigated (p. 61). CBET redistributes power from the ongoing central portion of the outgoing edge of OMEGA beams, significantly increasing the root-mean-squared absorption nonuniformity and reducing the total absorbed power and ablation pressure. A wavelength shift of ±10 Å on two legs is found to be optimal for absorption and close to optimal for absorption uniformity.

The 3-D hydrodynamic code *HYDRA* and the neutron tracking code *IRIS3D* were used to interpret neutron emission measurements (p. 100). It is shown that background subtraction is important for inferring areal density from backscattered neutrons, but less important for forward-scattered neutrons, and is important for inferring ion temperature from D–D neutrons, but is insignificant when inferring ion temperature from D–T neutrons at the areal densities typical of OMEGA implosions. Asymmetries resulting in fluid flow in the core are shown to influence the absolute inferred ion temperatures from both reactions. Relative inferred temperatures reflect the underlying asymmetry of the implosion and residual kinetic energy at stagnation.

Planar laser–plasma interaction (LPI) experiments on the NIF have for the first time allowed access to the regimes of electron density scale length (500 to 700 nm), electron temperature (3 to 5 keV), and laser intensity (6×10^{14} W/cm^2 to 16×10^{14} W/cm^2) that are relevant to direct-drive ICF ignition (see p. 140). Scattered-light data on the NIF show that the near-quarter-critical LPI physics appears to be dominated by stimulated Raman scattering rather than by two-plasmon decay. These results have significant implications for the mitigation of LPI hot-electron preheat in direct-drive–ignition designs.

An effective method for determining the offsets of the cryogenic implosion cores generated in OMEGA's ICF experiments was demonstrated (p. 146). This method utilizes images taken by the gated microscopic x-ray imaging diagnostic module. The cryogenic shot images are cross correlated onto images of their respective pulse-shape setup shot images. A true offset is then determined to be the average of the offsets calculated in the images, with the difference between those offsets being taken as the error. Initial offset results using this method indicate that the determined core offsets follow the core offsets at t_0.

Tomographic x-ray images of noncryogenic targets imploded in the direct-drive configuration on the 60-beam OMEGA laser were used to measure 3-D drive asymmetry in target modes $\lambda = 1$, 2, and 3 at a convergence ratio of ~3 (p. 152). Laser configurations were varied linearly with the corresponding modes. This made it possible to use the linear evolutions to determine the residual target mode amplitudes that remain when the laser beam energies are balanced and the laser mode-amplitude compensations are obtained. The analysis provides a means to determine the residual target modes (and the laser modes that compensate them) that agree with 3-D simulations, which predicts significant enhancements in fusion performance.

The first observation of CBET mitigation for direct-drive ICF implosions using wavelength detuning on the NIF has been reported. This article (p. 169) discusses the CBET results from two-beam energy exchange via seeded stimulated Brillouin scattering, which, as mentioned, detrimentally reduces ablation pressure and implosion velocity in direct-drive ICF. Direct-drive implosions on the NIF were conducted to reduce CBET by detuning the laser-source wavelengths (±2.3 Å UV) of the interacting beams over the equatorial region of the target. For the first time, wavelength detuning was shown experimentally to increase the equatorial region velocity by 16% and to alter the in-flight shell morphology. These experimental observations are consistent with design predictions of radiation–hydrodynamic simulations that indicate a 10% increase in the average ablation pressure.

2. Theoretical Design and Analysis

A significant portion of the cryogenic capsule implosion campaign in FY17 was dedicated to the 1-D implosion campaign used to develop a predictive model for direct-drive cryogenic implosions. The model includes a statistical mapping of the experimental results onto a simulation database of high-adiabat implosions ($\alpha \sim 5$) having convergence ratios of ~11 to 13. The nonlinear regression formula from the mapping is used to bridge the gap between experiments and simulations. Using this approach, neutron yields in this cryogenic capsule campaign have exceeded 10^{14} neutrons and areal densities have exceeded 100 mg/cm^2.

The effects of low-mode asymmetries on OMEGA direct-drive implosions using the 3-D Eulerian hydrodynamic code *ASTER* are analyzed beginning on p. 1. Beam-power balance, beam mispointing, beam mistiming, target offset, and variation in target-layer thickness are considered, using values determined from experimental measurements. *ASTER* indicates that implosion performance is mainly affected by target offset (~10 to 20 μm), beam-power balance ($\sigma_{rms} \sim 10\%$), and variation in target-layer thickness (~5%).

The impact of beam speckle and polarization smoothing on CBET is compared using the 3-D wave-based laser–plasma interaction code *LPSE* and ray-based models (p. 128). The results indicate that ray-based models underpredict CBET when the assumption of spatially averaged longitudinal incoherence across the CBET interaction region is violated. A model for CBET between linearly polarized speckled beams that uses ray tracing to solve for the real speckle pattern of the unperturbed laser beams within the eikonal approximation is presented. This model gives excellent agreement with wave-based calculations, suggesting that the impact of beam speckle on laser absorption calculations in ICF implosions is small (<1%).

Two novel target designs for using direct laser ablation (direct drive) on the NIF to assemble and ignite cryogenic fuel using the existing indirect-drive beam configuration are presented (p. 176). These two designs are the first ignition-relevant "polar" direct-drive target designs to include the physical effects of CBET between laser beams and nonlocal electron heat transport. A wavelength-detuning strategy is used to reduce scattered-light losses caused by CBET, allowing for ignition-relevant implosion velocities. The designs include: (1) a moderate-adiabat alpha-burning design with a D–T neutron fusion yield of 1.2×10^{17} and (2) a lower-adiabat ignition design with a gain of 27. Both designs have low in-flight aspect ratios, which imply improved hydrodynamic stability levels of perturbation growth during the implosion.

3. Diagnostics

During FY17, LLE installed and operated the single-line-of-sight time-resolved x-ray imager (TRXI) on OMEGA. TRXI is the result of a collaboration among General Atomics, Lawrence Livermore, LLE, and Sandia National Laboratories. The instrument was used on cryogenic capsule experiments and provided high-resolution (~10-μm spatial, ~40-ps temporal) imaging of highly compressed DT implosion cores. This enhanced imaging system will deliver significantly higher resolution than previously available, advancing stockpile stewardship diagnostics for ICF facilities throughout the Nuclear Security Enterprise.

Our LLE–LLNL collaborative effort demonstrated high-efficiency fifth-harmonic conversion of IR laser light. Initial tests were done using heated cesium lithium borate (CLBO) crystals and achieved 30% conversion efficiency. More recent tests use ammonium dihydrogen phosphate (ADP) coded to −70°C in a specially designed two-chamber cryostat. The fifth-harmonic beams will eventually be used to probe dense plasma using Thomson scattering.

A new technique to extract electron density profiles from angular filter refractometry (AFR) (p. 48) that makes use of a simulated annealing algorithm was developed. A seven-parameter function was chosen for the electron density and used to generate an AFR image that is compared to the measurement using a χ^2 test. The algorithm was applied to measurements of plasma expansion from a planar target and produced a fit with a statistical uncertainty of no more than 10% in the region of interest (10^{20} to 10^{21} cm^{-3}).

A 16-image Kirpatrick–Baez-type x-ray microscope coupled to a high-speed framing camera is described beginning on p. 79. A temporal resolution of ~30 ps and a spatial resolution of ~6 μm were achieved with this diagnostic. The new diagnostic makes it possible to accurately determine the cryogenic implosion core emission size and shape at the peak of the stagnation. This system was used to determine cryogenic capsule core pressures in excess of 50 Gbar.

Beginning on p. 184, we report on the linearity of the photostimulated luminescence process to make repeated image-plate scanning a viable technique to extract a more-dynamic range. To obtain a response estimate for second and subsequent scans with a BAS-MS image plate and the Typhoon FLA 7000 scanner, a new model for the readout fading of the image plate is introduced; it relates the depth distribution of activated photostimulated luminescence centers within the image plate to the recorded signal. Model parameters are estimated from an image-plate scan series for the hard x-ray image-plate diagnostic over a collection of experiments, providing x-ray energy spectra whose approximate shape is a double exponential.

4. Target Technology

A model for tritium interaction with metals was developed (p. 87) that can predict the temporal evolution of tritium concentration profiles during exposure to tritium gas, during storage and during successive decontamination efforts, and could be used to develop surfaces that are less prone to absorbing tritium. Operation of a tritium facility requires an understanding of the migration of tritium in metals.

Thermal contraction anomalies seen in glow-discharge polymer (GDP) capsules with a layer of an equimolar mixture of DT on their interior, compared to GDP with only deuterium and polystyrene capsules permeated with only DT, are discussed beginning on p. 159. Thermal contraction of the GDP-mixture capsules from cooling do not exhibit expected contraction and retain their room-temperature diameter after cooling. It is speculated that the highly cross-linked GDP shell is under compressive stress after fabrication and experiences bond breakage when exposed to high-density DT during permeation and some of this compressive stress is relieved during bond cleavage, causing the capsule's wall to swell, which counteracts contraction during cooling.

High-Energy-Density Science

During FY17, several high-energy-density science campaigns were conducted at the Omega Laser Facility including:

- measurements of the sound velocity and Grüneisen parameter in CH shocked to 800 GPa,

- equation-of-state measurements of CO_2 precompressed to 1.2 GPa and shock compressed to 980 GPa,

- the solid hP4 phase of Na was observed at ~320 GPa,

- Hugoniot measurements were conducted of Si shock compressed to 21 Mbar,

- a new high-pressure solid phase of dynamically compressed Al was observed, and

- in collaboration with Harvard University, the optical reflectance of dense hydrogen was measured as a function of energy in the 1.4- to 1.7-Mbar region and up to 2500 K. The data are consistent with the metallic hydrogen being a free-electron partially ionized plasma.

Picosecond time-resolved measurements of the shift of the $1s2p$–$1s^2$ line in He-like Al as a function of electron density are reported (p. 73). Temperature and density are inferred from the Al He_α complex using a nonlocal-thermodynamic equilibrium model. The measurements are broadly consistent with an analytic line-shift model based on calculations of a self-consistent field ion-sphere model.

In the article beginning on p. 13, we report on the evaluation of the equation of state of silicon using density-functional-theory dynamics simulations for densities from 0.001 to 500 gm/cm^3 and temperatures from 2000 to 108 K. This first-principles equation of state (FPEOS) is compared to *SESAME* 3810. The Hugoniot from FPEOS is ~20% softer than that from *SESAME* 3810 below 10^4 to 10^5 K, depending on density, and lower at higher temperatures. In *LILAC* simulations of a silicon-shell implosion, FPEOS gives ~30%-higher areal density and ~70%-higher neutron yield than *SESAME* 3810 because of the larger compressibility of silicon in FPEOS.

Lasers, Optical Materials, and Advanced Technology

LLE developed, constructed, installed, and activated a 100-J UV laser and Target Area System for the Dynamic Compression Sector at the Advanced Photon Source located at the Argonne National Laboratory near Chicago. This new research facility is operated by Washington State University (WSU) under sponsorship from the National Nuclear Security Administration (NNSA). LLE partnered with Logos Technologies to develop and build the high-energy laser, which is suitable for a broad range of applications.

A novel approach is introduced (p. 115) for controlling laser–plasma interactions that remove the need for long-focal-length systems or guiding structures to maintain high intensities over long distances and decouples the velocity of the focal spot from the group velocity of the light. This advanced focusing scheme, called a "flying focus," enables a small-diameter laser focus to propagate nearly 100× its Rayleigh length. By providing unprecedented spatiotemporal control over the laser focal volume, it allows the laser focus to co- or counter-propagate along its axis at any velocity.

A new laser-amplifier scheme has been proposed (p. 122) that will utilize stimulated Raman scattering in plasma in conjunction with a flying focus—a chromatic focusing system combined with a chirped pump beam that provides spatiotemporal control over the pump's focal spot. Simulations show that this enables optimization of the plasma temperature and mitigates many of the issues that are known to have impacted previous Raman amplification experiments, in particular the growth of precursors.

A time-to-frequency converter was constructed using an electro-optic phase modulator as a time lens, allowing the pulse shape in time to be transferred to the frequency domain (p. 192). The device was used to record the temporal shape of infrared pulses at a wavelength of 1053 nm (width about 7 ps) and to compare these measurements to those made by using both a streak camera and an autocorrelator. Numerical simulations were used to establish that the time-lens–based system can accurately measure the shape of infrared pulses between 3 and 12 ps. The numerical model was also used to determine how such a system can be modified to measure pulses whose width lies in the range of 1 to 30 ps—a range of interest for the OMEGA EP laser.

Omega Laser Facility Users Group

The Ninth Omega Laser Facility Users Group (OLUG) Workshop was held at LLE on 26–28 April 2017. It was attended by 110 researchers, including scientists, postdoctoral fellows, and students. The attendees represented institutions from five nations, including the United States, United Kingdom, France, Spain, and Hungary. The workshop included the presentation of invited talks, a talk on the NNSA perspective by Dr. Njema Frazier of ICF/NNSA, facility tutorials, poster papers, presentations on research at the national laboratories, and panel discussions. A summary of the OLUG Workshop is presented in an article starting on p. 198.

Education

As the only major university participant in the National ICF Program, education continues to be an important mission for LLE. The Laboratory's education programs cover the range from high school (p. 204) to graduate education.

1. High School Program

During the summer of 2017, 11 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, with an LLE advisor, 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. Three hundred and sixty-four high school students have now participated in the program since it began in 1989. Two of this year's program participants', Nikhil Bose and Yujia Yang, were named Science Talent Search "Scholars" in the prestigious Regeneron Science Talent search for the research projects they carried out at LLE. Bose developed a simulation model to explore a novel method of improving the performance of LLE's OMEGA EP laser and Yang carried out hydrodynamic simulations of a new fusion concept for the NIF. This year's students were selected from approximately 60 applicants to the program.

2. Undergraduate Student Program

Forty undergraduate students participated in work or research projects at LLE this past year. Student projects included 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 go on to pursue a higher degree in the area in which they gained experience at LLE.

3. Graduate Student Program

Graduate students are using the Omega Laser Facility as well as other LLE facilities for fusion and HED physics research and technology development activities (see Table I). These students are making significant contributions to LLE's research program. Twenty-six faculty members from five University of Rochester academic departments collaborate with LLE scientists and engineers. In FY17, 72 graduate students were involved in research projects at LLE, and LLE directly sponsored 47 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. Two of the 2017 LLE Ph.D. graduates are pursuing careers in NNSA programs. Dr. Michelle Gregor is now a post-doctoral fellow at Lawrence Livermore National Laboratory (LLNL) and Dr. Amanda Davis is an NNSA Graduate Fellow in the NNSA Defense Programs.

LLE also 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. Over 340 graduate students have now conducted their graduate research work at LLE since its graduate research program began.

In addition, 170 graduate students and post-graduate fellows from other universities have conducted research at the Omega Laser Facility as part of the NLUF program. Thirty-three graduate students (Table 152.VII, p. 211) and approximately 30 undergraduate students were involved in NLUF research programs in FY17.

FY17 Omega Laser Facility Operations

During FY17, the Omega Laser Facility conducted 1353 target shots on OMEGA and 785 target shots on OMEGA EP for a total of 2138 target shots (see Tables 152.IV and 152.V, p. 206). OMEGA averaged 10.7 target shots per operating day with Availability and Experimental Effectiveness averages for FY17

Table I: University of Rochester graduate students conducting research at LLE in FY17.

Student Name	Dept.	Faculty Advisor	LLE Advisor	Funding	Research Area	Status
M. B. Adams	PAS	P.-A. Gourdain		Horton	Numerical studies of instabilities in plasma jets generated by the laser ablation of DT ice	
Y. E. Akbas	PAS	R. Sobolewski		Other	Intrinsic nanostructures: asymmetric nanochannel devices	
D. H. Barnak	PAS	R. Betti		Horton	Applications of magnetic fields in high-energy-density physics	
D. Bassler	CHEM	W. U. Schröder		Other	Radiochemistry of tritium transport	
K. Bauer	OPT	R. Brown and M. A. Alonso	J. D. Zuegel	Horton	351-mm characterization of scatter from distributed polarization rotator concepts for polar direct drive at the National Ignition Facility (NIF)	
M. Berkgoetter	OPT	B. E. Kruschwitz		Other	Phase retrieval	
A. Bose	PAS	R. Betti		Horton	Implosion dynamics of direct-drive targets in the presence of magnetic fields	Graduated (postdoc Univ. of Michigan)
S. Buch	OPT	G. P. Agrawal and W. R. Donaldson		Other	Nonlinear effects in multimode fibers	
S. Bucht	PAS	D. H. Froula		Horton	Novel 1200-nm high-power laser beams for laser-plasma amplification	
L. E. Bukowski	OPT	W. H. Knox	J. D. Zuegel	Horton	Terahertz detection and imaging with ultra-broadband high-energy lasers	
E. Burnham-Fay	ME	J. D. Ellis	D. W. Jacobs-Perkins	Horton	Active vibration stabilization of NIF-scale direct-drive cryogenic targets	Defending Feb. 2018
J. Cady	ECE	R. Sobolewski		Other	Ultrafast semiconductor devices	M.S. expected May 2018
G. Chen	MSC	R. Sobolewski		Other	Time-domain THz spectroscopy	
Z. Chen	PAS	A. Frank		Horton	Evolution of binary stars	
D. A. Chin	PAS	G. W. Collins and J. R. Rygg	T. R. Boehly	Other	Using extended x-ray absorption fine structure to characterize highly compressed matter	
B. P. Chock	CE	D. R. Harding		Horton	Enhancing electric-field–enabled droplet motion for target production	Defending Jan. 2018
A. R. Christopherson	ME	R. Betti		Horton	Measuring and understanding hydrodynamic performance of cryogenic implosions on the OMEGA laser	
L. Crandall	PAS	J. R. Rygg and G. W. Collins	T. R. Boehly	Horton	Equation of state of planetary fluids	
C. Danly	ME		S. P. Regan	Other	Implosions, stagnation, and neutron-imaging diagnostics	
A. Davies	PAS	D. H. Froula	D. Haberberger	Horton	Ultrafast measurements of electron temperature in a laser-plasma amplifier	
A. K. Davis	PAS	D. H. Froula	D. T. Michel	Horton	Three-dimensional measurements of direct-drive implosions with low-mode nonuniformities	Graduated (NNSA Fellow)
Y. Ding	ME	R. Betti	S. X. Hu	Horton	First-principles investigations on transport and optical properties of high-energy-density plasmas	

Table I: University of Rochester graduate students conducting research at LLE in FY17 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Funding	Research Area	Status
T. Eckert	PAS	P.-A. Gourdain	C. Forrest	Horton	Experimental nuclear physics	
M. Evans	PAS	P.-A. Gourdain		Horton	Experimental study of instabilities in plasma jets generated by laser ablation of DT ice	
C. Fagan	CHEM	W. U. Schröder		Other	Surface effects in tritium absorption	
P. Franke	PAS	D. H. Froula		Horton	Control of ionization wave propagation with a flying focus	
J. M. Garcia-Figuero	CE	D. R. Harding		Horton	Manufacture of low-atomic-number nonpolymeric materials	
M. Gates	ECE	R. Sobolewski		Other	TBD	
M. K. Ginnane	ME	J. R. Rygg and G. W. Collins	T. R. Boehly	Other	Novel diagnostics to study highly compressed matter	
X. Gong	ME	G. W. Collins and J. R. Rygg	J. R. Rygg	Horton	Structural and optical changes in ramp-compressed alkalais	
V. Gopalaswamy	ME	R. Betti		Other	Hydrodynamics in 1-D physics campaigns	
M. C. Gregor	PAS	G. W. Collins	T. R. Boehly	Horton	Properties of matter that are shocked and compressed to high-energy densities using high-power lasers	Graduated (LLNL Fellow)
A. Hansen	PAS	D. H. Froula		Horton	Nonlinear cross-beam energy transfer physics	
R. J. Henchen	ME	D. H. Froula		Horton	Hydrodynamic gradients in underdense plasmas	
B. J. Henderson	PAS	G. W. Collins and J. R. Rygg	T. R. Boehly	Horton	Optical properties of compressed matter deduced from reflectivity measurements	
J. Hinz	PAS	S. X. Hu		Other	Using machines to learn to improve the free-energy functionals	
M. Huff	PAS	J. R. Rygg and G. W. Collins	T. R. Boehly	Other	Measurements of sound speed in shock-compressed materials	
G. Jenkins	OPT	J. Bromage		Horton	Broadband seed generation and amplification at high-average powers	
B. Lam	OPT	J. Shojaie		Other	Laser–plasma interactions (LPI) in magnetized plasmas	
L. Leal	PAS	R. Betti and A. V. Maximov		Other	Plasma physics	
A. Lees	ME	H. Aluie		Horton	High-performance code development	
S. Li	PAS	A. Frank		Other	Heterogeneous flow in an interstellar medium	
W. Liu	ME	C. Ren	C. Ren	Horton	Magnetic fields and their effects on LPI	
N. Luciani	ME	R. Betti		Other	Implosion physics	
O. M. Mannion	PAS	S. Y. BenZvi	C. J. Forrest and J. P. Knauer	Horton	Moment analysis of neutron spectra	
A. L. Milder	PAS	D. H. Froula		Horton	Measurement of electron distribution function using collective Thomson scattering	
S. C. Miller	ME	V. N. Goncharov	P. B. Radha	Horton	Hydrodynamics of ICF implosions	
Z. L. Mohamed	PAS	D. H. Froula	J. P. Knauer	Horton	Gamma emission from fusion reactions	

Table I: University of Rochester graduate students conducting research at LLE in FY17 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Funding	Research Area	Status
D. Patel	ME	R. Betti	V. N. Goncharov	Horton	Hybrid direct–indirect drive for ICF	
R. Paul	ME	S. X. Hu		Horton	High-pressure phase diagram of material	
B. W. Plansinis	OPT	G. P. Agrawal and W. R. Donaldson		Horton	Single-shot shape detection of picosecond pulses using four-wave mixing inside optical fibers	Graduated Sept. 2017 (currently at Harris Corp.)
D. N. Polsin	PAS	G. W. Collins	T. R. Boehly	Horton	Observation of a new high-pressure solid phase in dynamically compressed aluminum	
J. J. Ruby	PAS	G. W. Collins	J. R. Rygg	Horton	Equation-of-state measurements using convergent shocks	
R. Saha	PAS	J. R. Rygg and G. W. Collins	T. R. Boehly	Horton	Measurement of compressed matter using Thomson scattering	
D. Saulnier	CE	K. L. Marshall and M. Anthamatten		Horton	Liquid crystal chiroptical polarization rotators for the near-UV region	
E. M. Schiesser	OPT	J. Rolland	S.-W. Bahk	Horton	Applying freeform optics to scalable, compact beamlines	
A. Schwemmlein	PAS	W. U. Schröder	J. P. Knauer	Horton	Thermonuclear fusion and breakup reactions between light nuclei	
J. R. Serafini	PAS	R. Sobolewski		Horton	Ultrafast optical and electronic characterization of (Cd,Mg)Te single crystals	Graduated (postdoc RIT)
A. Shramuk	ECE	R. Sobolewski		Other	Superconducting optoelectronic devices	M.S. graduated (in law school)
R. Shrestha	ECE	R. Sobolewski		Other	Terahertz time-domain spectroscopy of carbon nanotubes	M.S. graduated May 2017
J. Slater	OPT	J. Bromage		Other	Characterization of DKDP crystals using spatially resolved Raman spectroscopy	
Z. Sprowal	PAS	G. W. Collins and J. R. Rygg	T. R. Boehly	Other	High-energy-density physics	
C. R. Stillman	PAS	D. H. Froula	P. M. Nilson	NNSA Fellow	Hot dense matter	
G. Tabak	PAS	G. W. Collins and J. R. Rygg	M. Zaghoo	Horton	Study of precompressed materials using shock compression	
N. D. Viza	CE	D. R. Harding		Horton	Integrated "lab-on-chip" microfluidic device for manufacturing foam targets	Defending Jan./Feb. 2018
M. Wang	CE	D. R. Harding		Horton	Use of two-photon polymerization to "write" millimeter-size structures with micron resolution	
I. West-Abdallah	PAS	G. W. Collins and J. R. Rygg	T. R. Boehly	Other	High-energy-density physics	
K. M. Woo	PAS	R. Betti		Horton	Three-dimensional ablative Rayleigh–Taylor instability	
E. Wright	PAS	D. H. Froula	W. Theobald	Other	Direct measurements of wave breaking using Thomson scattering	

Table I: University of Rochester graduate students conducting research at LLE in FY17 (continued).

Student Name	Dept.	Faculty Advisor	LLE Advisor	Funding	Research Area	Status
J.-C. Yang	CE	M. Anthamatten		Horton	Crystallization in shape-memory polymer networks	
D. Zhao	ME	H. Aluie		Horton	Analyzing multiscale physics of multimode and turbulent Rayleigh–Taylor hydrodynamics	
Y. Zhao	MS	W. R. Donaldson		Horton	Fabrication and testing of AlGaN photodiodes	

CE: Department of Chemical Engineering
CHEM: Department of Chemistry
ECE: Department of Electricial and Computer Engineering
ME: Department of Mechanical Engineering
MSC: Department of Materials Science
OPT: The Institute of Optics
PAS: Department of Physics and Astronomy

of 95.7% and 94.4%, respectively. OMEGA EP was operated extensively in FY17 for a variety of internal and external users. A total of 773 target shots were taken in the OMEGA EP target chamber and 12 joint target shots were taken in the OMEGA target chamber. OMEGA EP averaged 8.7 target shots per operating day with Availability and Experimental Effectiveness averages for FY17 of 95.8% and 96.6%, respectively. Per the guidance provided by DOE/NNSA, the facility provided target shots for the ICF, HED, NLUF, and LBS programs. The facility also provided a small number of shots for Commissariat à l'énergie atomique et aux energies (CEA), Centre Lasers Intenses et Applications (CELIA), and ARPA-E programs (see Figs. 1 and 2). Nearly 70% of the target shots in FY17 were taken for the ICF and HED programs.

Details of this work are contained in an article beginning on p. 206. Highlights of the Omega Laser Facility activities in FY17 included the following:

- The 100-Gbar Campaign worked to achieve higher implosion pressures through improved laser power balance and a cryogenic fill-tube target system.

- To mitigate CBET, a tunable wavelength UV beam will be produced by one of the OMEGA EP beams. This beam will be injected into OMEGA to study CBET mitigation via wavelength detuning (up to 30 Å).

- Various improvements to the laser systems were implemented in FY17 including a new ultrafast temporal diagnostic and a time-multiplexed pulse-shaping system to OMEGA EP, and an improved smoothing by spectral dispersion spectrometer on OMEGA.

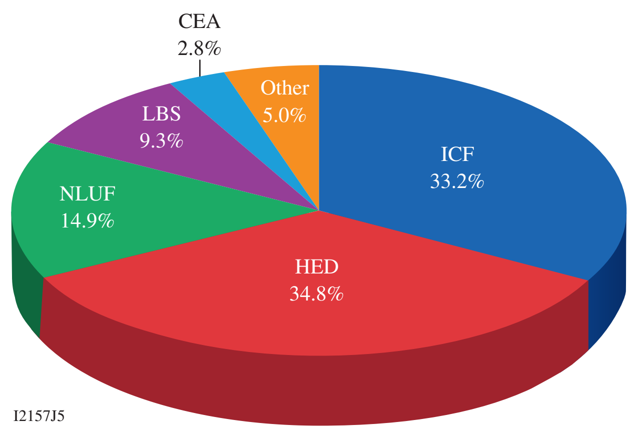

Figure 1
Distribution of Omega Laser Facility target shots by program in FY17.

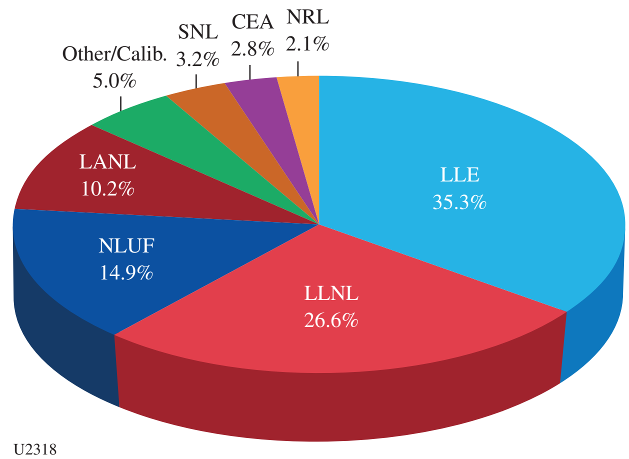

Figure 2
Institutional distribution of Omega Laser Facility target shots in FY17.

- Target diagnostic improvements included a high-resolution spectrometer that was implemented on OMEGA EP; a single line-of-sight, time-resolved x-ray imager was developed in collaboration with General Atomics, LLNL, Sandia National Laboratories (SNL), and Kentech Instruments and deployed on OMEGA; an improved signal-to-noise ratio neutron time-of-flight diagnostic was deployed on port H10; and a powder x-ray diffraction diagnostic is being upgraded to acquire time-resolved images.

National Laser Users' Facility and External Users Programs

The Fundamental Science Campaigns accounted for nearly 24% of the Omega Laser Facility target shots taken in FY17. Nearly 62% of these shots were taken for experiments for the NLUF Program, and the remaining shots were allotted to the LBS Program, comprising peer-reviewed fundamental science experiments conducted by the national laboratories and by LLE.

The Omega Laser Facility was also used for several campaigns by teams from CEA of France. These programs are conducted at the facility on the basis of special agreements put in place by DOE/NNSA and participating institutions.

The facility users during this year included 13 collaborative teams participating in the NLUF Program; 14 teams led by Los Alamos National Laboratory (LANL), LLNL, and LLE scientists participating in the LBS Program; many collaborative teams from the national laboratories [LANL, LLNL, SNL, and Naval Research Laboratory (NRL)] and LLE conducting ICF experiments; investigators from LLNL, LANL, and LLE conducting experiments for high-energy-density–physics programs; and scientists and engineers from CEA and CELIA. Nearly 60% of the facility target shots were provided to external users.

1. FY17 NLUF Program

During the first quarter of FY17, the Inertial Fusion Office of DOE/NNSA completed a solicitation, review, and selection process for NLUF experiments to be conducted at the Omega Laser Facility during calendar years 2017 and 2018. Twenty-eight proposals were submitted in response to the call for proposals and the shot requests totaled 60.5 shot days at the Omega Laser Facility. The proposals were peer reviewed by an independent review committee and ICF/NNSA selected 13 proposals for funding and shot allocation for the period calendar years 2017 and 2018. These NLUF projects (see Table 152.VI, p. 210) were allotted Omega Laser Facility shot time and conducted 319 target shots at the facility. The FY17 NLUF experiments are summarized beginning on p. 209.

2. FY17 Laboratory Basic Science Studies

Sixteen LBS projects previously approved for FY17 target shots were allotted Omega Facility shot time and conducted a total of 199 target shots at the Omega Facility in FY17 (see Table 152.VII, p. 230). The FY17 LBS experiments are summarized beginning on p. 230.

During FY17, LLE issued a solicitation for LBS proposals to be conducted in FY18. A total of 28 proposals were submitted. An independent review committee reviewed and ranked the proposals; on the basis of these scores, 16 proposals were allocated 21 shot days at the Omega Laser Facility in FY18. Table 152.IX, p. 231 lists the approved FY18 LBS proposals.

3. FY17 LLNL Experimental Programs

In FY17 LLNL's HED Physics and Indirect-Drive Inertial Confinement Fusion (ICF-ID) Programs conducted numerous campaigns on the OMEGA and OMEGA EP Laser Systems. Overall, these LLNL programs led 413 target shots in FY17, with 282 shots using only OMEGA and 131 shots using only OMEGA EP. Approximately 27% of the total number of shots (78 OMEGA shots and 35 OMEGA EP shots) supported the ICF-ID Campaign. The remaining 73% (204 OMEGA shots and 96 OMEGA EP shots) were dedicated to experiments for HED physics. Highlights of the various HED and ICF-ID Campaigns are summarized beginning on p. 242.

In addition to these experiments, LLNL Principal Investigators (PI's) led a variety of Laboratory Basic Science Campaigns using OMEGA and OMEGA EP, including 85 target shots using only OMEGA and 70 shots using only OMEGA EP.

Overall, LLNL PI's led a total of 568 shots at LLE in FY17. In addition, LLNL PI's also supported 30 NLUF shots on OMEGA and 46 NLUF shots on OMEGA EP, in collaboration with the academic community.

4. FY17 LANL Experimental Campaigns

In FY17, LANL carried out 17 shot days comprising 218 target shots on the OMEGA and OMEGA EP Laser Systems in the areas of HED science and ICF. In HED, the LANL focus was on areas of radiation flow, hydrodynamic turbulent mix and burn, warm-dense-matter equations of state, and coupled Kelvin–Helmholtz/Richtmyer–Meshkov instability growth. For ICF, the campaigns focused on the Priority

Research Directions (PRD's) of implosion phase mix and stagnation and burn, specifically as they pertain to laser direct drive (LDD). Several focused shot days were also dedicated to transport properties in the kinetic regime. In addition, LANL continues to develop advanced diagnostics such as neutron imaging, gamma reaction history, and gas Cherenkov detectors at the Omega Laser Facility.

5. FY17 SNL Experimental Campaigns

During FY17, SNL conducted a total of four shot days (one on OMEGA and three on OMEGA EP) aimed at characterizing the laser heating of underdense plasmas (D_2, Ar) at parameters that are relevant to the MagLIF ICF scheme. In total these accounted for 44 target shots at the facility. Reports on these campaigns are on p. 280.

6. FY17 NRL Experimental Campaigns

During FY17, the NRL/LLE collaboration on laser imprint led to three successful shot days on OMEGA EP. The experiments showed that the application of a prepulse that pre-expands and lifts off the coating prior to the arrival of the main laser pulse gives an order of magnitude reduction of laser imprint, as expected on the basis of the original experiments on the Nike laser and an understanding of the mechanism of the imprint suppression. Further experiments demonstrated imprint reduction with prepulse times compatible with pulse durations available for implosions on OMEGA. LLE is evaluating the implementation of a suitable prepulse for imprint reduction with NRL.

7. FY17 CEA Experiments

During FY17 CEA conducted 59 target shot experiments at the Omega Laser Facility (four shot days on OMEGA and one on OMEGA EP). The experiments included studies of rugby hohlraums in preparation for Laser Mégajoule campaigns, measurements of the Hugoniot of LiH, spectroscopy of direct-drive implosions, studies of beam propagation in gas-filled cavities, and laser–plasma interaction experiments. Some of these experiments are described (p. 282).

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