Section 1
THE OMEGA UPGRADE

Part I: Theory and Design

The objective of the U. S. Inertial Confinement Fusion (ICF) Program is to develop a laboratory microfusion capability for military and energy-production applications. Attaining the objectives of the ICF program depends critically on understanding the physics of thermonuclear ignition and burn. The development of the required ICF physics data base depends to a large extent on the experimental target-implosion programs being carried out on the NOVA laser at Lawrence Livermore National Laboratory (LLNL) and the OMEGA laser at the University of Rochester Laboratory for Laser Energetics (LLE). With an energy capability of 100,000 J, the NOVA laser is the primary laboratory driver for the U.S. ICF program and is being used to carry out x-ray-driven ICF target-implosion experiments. OMEGA, a 4,000-J, uniform-illumination laser, is the primary U.S. facility used to explore the feasibility of the direct-drive approach to ICF. Both of these experimental programs have demonstrated high-density compression of fusion capsules—a key requirement for the eventual success of ICF.

While the current OMEGA experiments are important in addressing many key ICF issues, a higher-energy, direct-drive capability provided by an upgrade of this laser, would achieve sufficient thermonuclear yield to address ignition-scaling issues. These experiments could increase the confidence level associated with the success of a national high-gain laboratory facility. Preliminary design engineering and development and related studies for the upgrade of the OMEGA facility are currently in progress. In this and the following issue of the LLE Review, we review the present status of the OMEGA Upgrade design engineering and development effort, including a conceptual design of the upgrade.

Purpose of the Proposed OMEGA Upgrade

There are two approaches to inertial fusion: indirect (or hohlraum) drive and direct drive. The indirect-drive approach, which involves the conversion of the driver energy into x rays to drive a fuel capsule, is the main-line approach of the U.S. national program and is being pursued at LLNL and the Los Alamos and Sandia National Laboratories. Direct drive involves the direct irradiation of a fuel pellet by energy from the driver (laser or particle beam) and may be energetically more efficient than indirect drive.

The direct-drive approach to short-wavelength laser fusion is not only an alternative approach to inertial fusion, but also an essential tool for obtaining the capsule-physics technical base required to understand critical ICF issues. The next critical issue in ICF to be addressed, after the demonstration of high-density and high-convergence implosions, is the production of a small region of plasma at ignition temperature and density. Ignition refers to the rapid thermonuclear burning of fusion fuel that simultaneously achieves high density and temperature to trigger the reaction. Once ignition occurs, high-energy thermonuclear-reaction products redeposit their energy in cold, unignited thermonuclear fuel surrounding the region and cause a thermonuclear burn wave to propagate. It is the propagation of the burn wave that is responsible for high gain. If the required degree of drive uniformity is achieved, it may be possible with direct drive to achieve high-density target compression and thermonuclear ignition conditions with less laser energy than is required to carry out hohlraum-driven implosions. Achievement of these conditions would strongly support the feasibility of a high-gain facility.

The LLE OMEGA laser is the only major facility in the United States capable of currently conducting fully diagnosed, symmetric, direct-drive, spherical implosion experiments. The 1986 National Academy of Sciences (NAS) Report of the Committee for a Review of the Department of Energy's Inertial Confinement Fusion Program concluded that if the LLE program achieved the challenging goal of attaining 100–200 times liquid DT density in compression experiments, they would support a 30,000-J upgrade of OMEGA for the purpose of demonstrating significant thermonuclear burn via direct drive. Calculations indicate that a 30,000-J, ultraviolet (UV) laser system could produce implosions in the ignition regime (see Fig. 38.1). In addition, such a facility could support a number of multi-laboratory collaborative experiments to investigate many important ICF issues, such as ignition scaling, fuel-pusher interface mix, preheat, and hydrodynamic instabilities.

In 1988, the objective of 100–200 times liquid DT density was attained on the OMEGA laser with cryogenic fuel targets; high compression was verified using a number of independent measurement

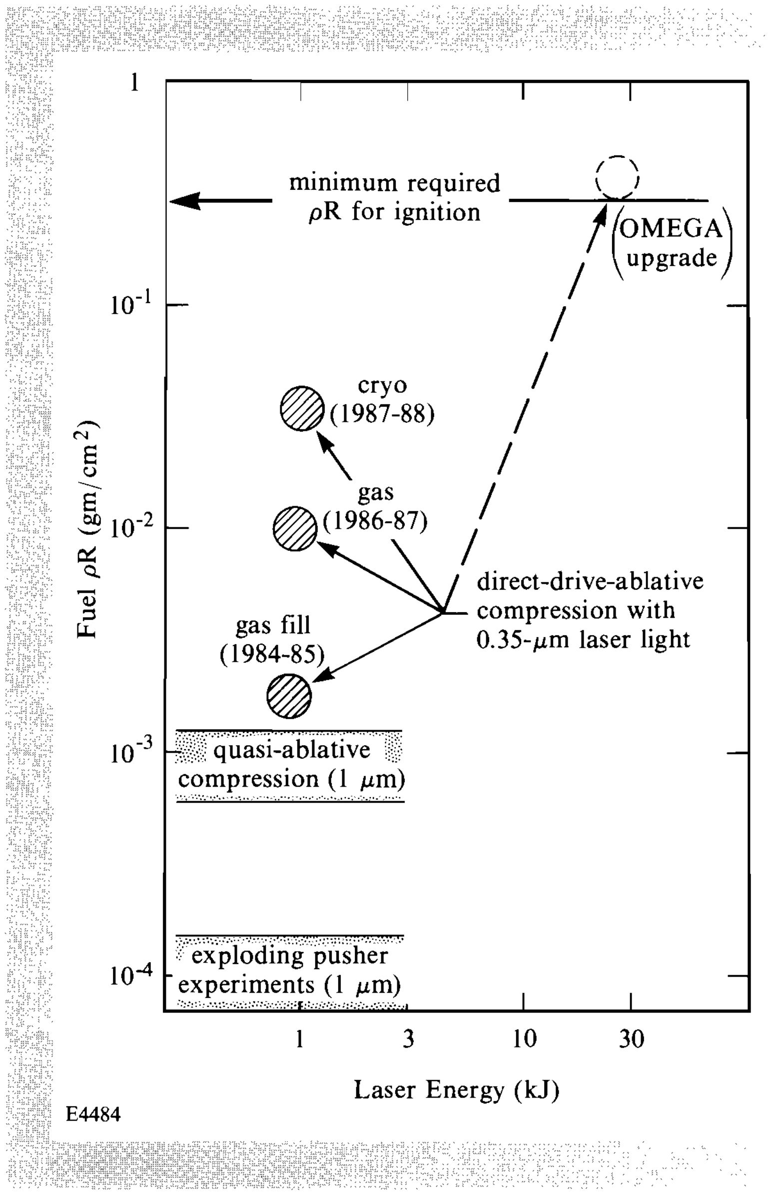

Fig. 38.1
The quality of fuel confinement for inertial fusion is the fuel areal density—the product of fuel density ρ (in grams per cubic centimeter) times the compressed fuel radius R (in centimeters). Thermonuclear microcore ignition requires a fuel-ρR product in excess of 0.3 g/cm^2 at temperatures higher than 5,000 eV. The progress of direct-drive ablative compression on the OMEGA laser in achieving the required degree of fuel compression (ρR) is shown. OMEGA experiments at 1,000 J–1,500 J with cryogenic-fuel-layer targets have demonstrated a fuel ρR of 0.03 gm/cm^2. Near-ignition conditions could be achieved by the upgraded OMEGA laser operating at a level of 30,000 J.

techniques. These experiments were the result of an intensive effort, which included (a) improvements of the target surface distribution of laser irradiation on the OMEGA laser; (b) the development and implementation of a new class of diagnostic instrumentation to measure high-density implosions; and (c) the implementation of cryogenic fuel-layer technology on the OMEGA facility. The results of these experiments were validated by a DOE-selected panel of scientists from other ICF laboratories.

The proposed upgrade of the OMEGA facility is based on the Nd:glass laser technology developed over the last decade by LLNL and LLE. Preliminary design engineering and development and studies of the upgrade to OMEGA began in FY88; full implementation of the facility could occur by 1992. The cost estimates initially proposed (final estimates to be defined by the design study) are $39,000,000 (in

FY88 dollars) [or a total of $44,120,000 in as-spent dollars]. A key objective of the upgrade engineering design is to keep the added operating costs of the facility as low as possible.

Program Plan for the OMEGA Upgrade

Direct drive for laser fusion provides a singular opportunity to define the minimum energy required to build a successful ICF facility. As the principal focus of the DOE research on direct drive, the whole research effort at LLE is designed to address the important questions of driver and target performance needed to produce high-density implosions. The four elements of the LLE direct-drive ICF program are

1. OMEGA Upgrade engineering and development,
2. OMEGA experiments and laser operations,
3. target fabrication, including cryogenic fuel-layer capsule development, and
4. high-density target diagnostic development and implementation.

Modifications to the OMEGA facility include implementation of pulse-shaping systems; multibeam pulse-shape diagnostics; beam-uniformity improvements; and the design, development, fabrication, and activation of a 30,000-J upgrade to the OMEGA laser. The engineering design effort for this element will be completed this year. Full implementation of the OMEGA upgrade could begin in FY90 with completion by FY92, according to the schedule illustrated in Fig. 38.2.

In planning the OMEGA upgrade, LLE will continue to emphasize Nd:glass laser technology. Primary emphasis will be on designing and testing high-efficiency amplifier modules for potential use in the upgrade. LLE will be collaborating with LLNL on this effort; in one aspect of this collaboration, LLE will evaluate a version of a LLNL-proposed disk amplifier for use on the upgraded laser. The development of measurement and design techniques for improving the quality of glass drivers will be continued. The LLE engineering division will investigate new and improved methods of producing optical components, such as mirrors, polarizing elements, mechanical supports, phase plates, and other systems needed to operate large fusion-laser systems. In addition to creating an enhanced experimental capability, the upgrade of the OMEGA laser will provide the opportunity to augment the ICF driver-development effort and to test many advanced glass-laser concepts relevant to a laboratory high-gain facility.

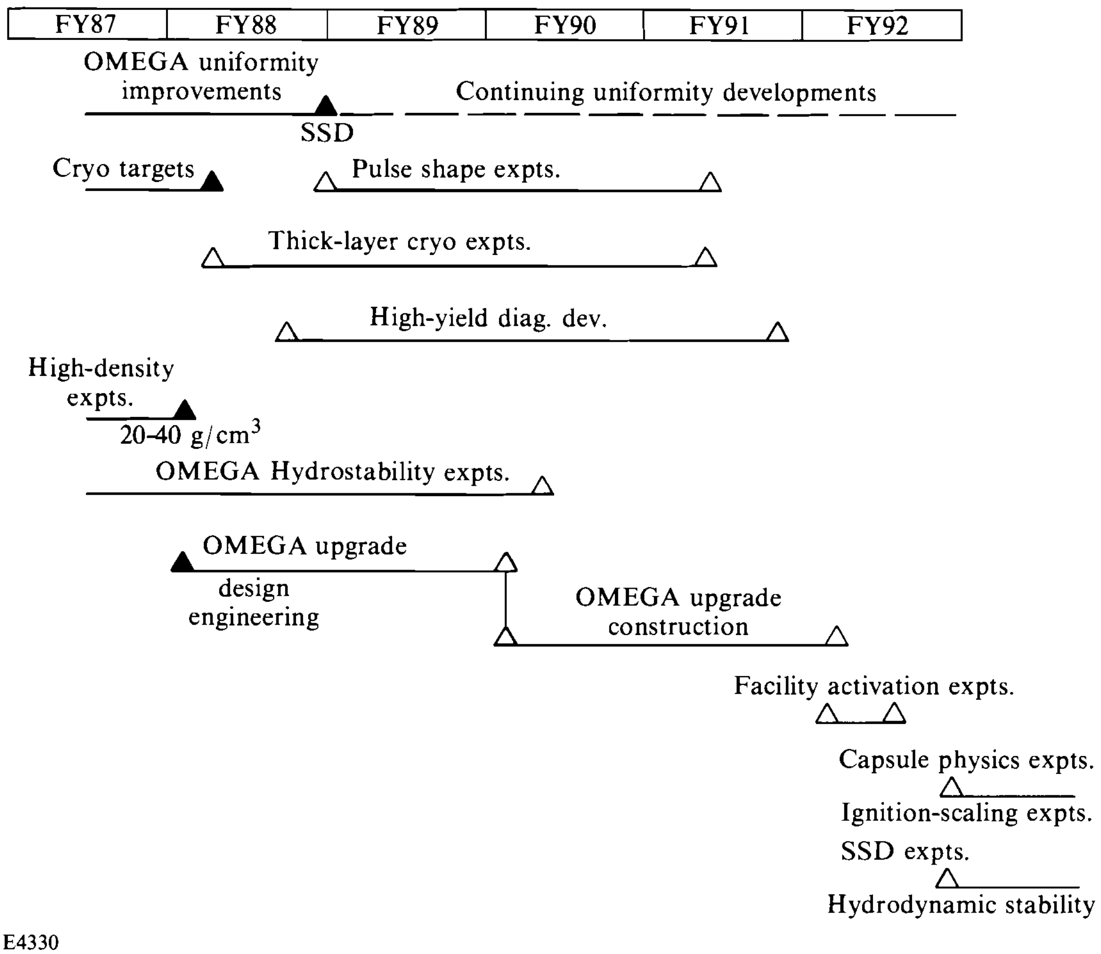

Fig. 38.2
Schedule for the LLE direct-drive laser-fusion program including the upgrade of the OMEGA laser system.