S-AA-M-12

OMEGA
System Operations Manual
Volume I–System Description

Chapter 1: System Overview

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Chapter 1
System Overview

1.0 INTRODUCTION

This document describes the design and summarizes the operation of the OMEGA laser system. An upgrade project undertaken from October 1990 to May 1995 consisted of a complete overhaul of the building and laser facility. Prior to the upgrade, OMEGA was a 24-beam, 2-kJ, 351-nm laser. After the upgrade, OMEGA has 60 beams and can deliver up to 30 kJ of 351-nm laser energy. The upgrade took 4.5 years and $61M to complete. The OMEGA system provides a unique capability to validate high-performance, direct-drive laser-fusion targets. The ultimate goal of the Laboratory for Laser Energetics (LLE) experimental program on OMEGA is to study the physics of hot-spot formation under near-ignition conditions (ignition scaling), using cryogenic targets whose hydrodynamic behavior scales to that of high-gain targets. Performance goals of these experiments are the achievement of a convergence ratio (C_R) = 20, compressed fuel ion temperature (T_i) of 2 to 3 keV, and a total fuel density–radius product (ρR) in excess of 0.2 g/cm^2 for targets whose Rayleigh–Taylor growth factors are in excess of 500.

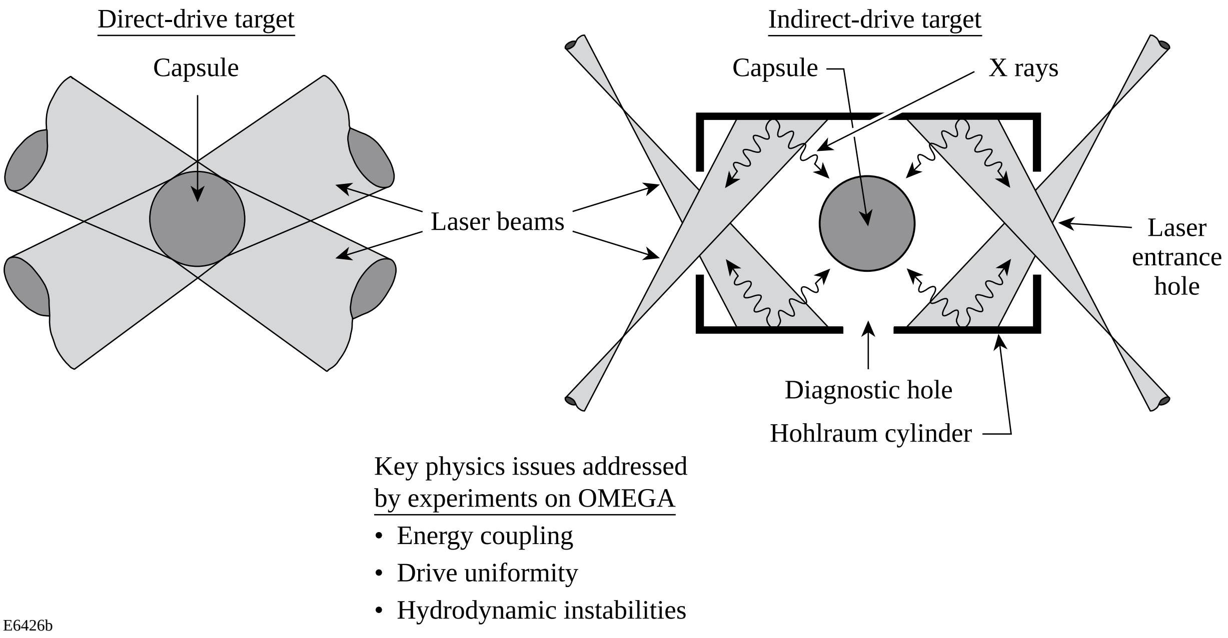
In addition to the LLE direct-drive mission, the facility time is allocated to DOE users from Lawrence Livermore National Laboratory (LLNL), Los Alamos National Laboratory (LANL), Naval Research Laboratory (NRL), and Sandia National Laboratory (SNL). System time is also allocated for a variety of users through the National Laser Users' Facility (NLUF), which is managed by LLE. The goals of these users vary greatly but are generally focused on the physics associated with indirect-drive irradiation and on diagnostic development.

Many key physics issues associated with capsule implosions are common to both direct and indirect drive. Studies of drive uniformity, hydrodynamic instabilities, and energy coupling to the capsule are relevant to either approach. [Direct and indirect drive refers to the way the laser couples to the target (see Fig. 1.0-1)]. The OMEGA facility is central to developing an early understanding of the expected target performance under conditions that will be available with the National Ignition Facility (NIF), a 192-beam laser currently under construction at LLNL. NIF is expected to begin preliminary target shot operations in 2004, and until that time, OMEGA is the principle facility for conducting preparatory experiments.

1.1 SYSTEM PERFORMANCE REQUIREMENTS

The system is installed in the space previously occupied by the 24 beam OMEGA laser and capitalizes on the experience gained over ten years of system operations. The uniformity, total-energy, and pulse-shaping requirements for the ignition-scaling experiments call for a 60-beam system to produce 30 kJ on target in temporally shaped pulses with peak powers of up to 45 TW. The top-level specifications are given in Table 1.1-1.

The on-target energy goal is dictated by the requirement to conduct hydrodynamically equivalent capsule implosions that produce diagnostic signatures sufficient to adequately diagnose the fuel-core performance. Short-wavelength (351-nm) ultraviolet laser light has long been attractive as a laser-fusion driver due to its enhanced absorption and reduced hot-electron production. The use of Nd:glass



Key physics issues addressed by experiments on OMEGA

- Energy coupling
- Drive uniformity
- Hydrodynamic instabilities

Figure 1.0-1
Direct-drive targets are driven by laser irradiation that impinges directly on the capsule. Indirect-drive targets are compressed by x rays generated when the laser impinges on a cylindrical “hohlraum” that surrounds the target.

Table 1.1-1
OMEGA Specifications

Energy on target	Up to 30 kJ in a 1-ns square pulse
Wavelength	351 nm (third harmonic of Nd:glass)
Lasing medium	Nd-doped phosphate glass
Number of beams	60
Irradiation nonuniformity	1%–2%
Beam-to-beam energy balance	Less than 4% rms on target
Beam-to-beam power balance	< 1% @ peak
Beam smoothing	• Spectral dispersion • Polarization smoothing • Phase smoothing
Pulse shaping	0.1- to 4-ns arbitrary shapes with 40:1 contrast
Repetition rate	One shot/h
Laser and diagnostic pointing	Any location within 1 cm of chamber center

was predetermined by the original requirement of upgrading the original 24-beam OMEGA system. The Nd:glass master-oscillator/power amplifier system produces 60 beams of infrared energy (1054 nm). Each beam is converted to the ultraviolet at the end of the amplifiers prior to being delivered to the target. The optical assembly that performs this conversion is referred to as the frequency-conversion crystal (FCC) subsystem.

The uniformity of the laser has two parts; first, each beam must produce a uniform spot on target, and second, the beam-to-beam power variation on target must be kept to a minimum. On-target uniformity benefits from the 60-beam configuration because the power delivered to any given point on a spherical target has contributions from many beams. As a result of the beams overlapping on target, a beam-to-beam energy balance of 3%–4% is sufficient to produce an on-target irradiation uniformity of 1%–2%. Power balance is achieved by ensuring that the time history of the arrival of the energy at the target is the same for each beam. This is achieved by minimizing the beam-to-beam variation of the gain produced by each amplification stage and by equalizing the time of arrival on target.

The instantaneous uniformity of the energy within a given beam spot on the target is optimized by the application of the three smoothing techniques listed in Table 1.1-1. Smoothing by spectral dispersion (SSD) is a technique that modulates the wavelength of the master-oscillator pulse. This causes the speckle points within the on-target spot to move during the period of irradiation. Polarization smoothing is achieved by passing the UV beam through a distributed phase rotator (DPR) optic as it propagates to the target. This effect works in conjunction with a distributed phase plate (DPP) optic to produce multiple focus spots on the target.

A versatile capability to produce temporally shaped pulses is also needed to minimize hydrodynamic instabilities in the implosions. Finally, the system repetition rate of one shot per hour facilitates a productive experimental program.

1.2 LASER-ENERGY PERFORMANCE

A variety of ultraviolet (UV) pulse shapes that tailor the target drive for a specific experiment are available. While the infrared (IR) performance is relatively independent of the pulse shape, UV power is strongly dependent on shape because the conversion to UV is a nonlinear, intensity-dependent process. The system performs nearly optimally with a 1-ns square pulse, which is to say that maximum UV energy can be delivered to the target with a 1-ns square pulse.

The overall energy performance predicted for a 1.0-ns square pulse on OMEGA is shown in Table 1.2-1. This table outlines the performance for the cases of no-SSD bandwidth and for 1.0-THz-SSD bandwidth at nominal system peak power and with the best IR to UV conversion setting. The energies quoted are summed over the 60 beams and reflect 0.84-kJ IR per beam prior to conversion. The UV on-target numbers include a 4.1% loss at the UV diagnostic pickoff and an additional 8% loss due to the transport system, including transport mirrors, DPR's, DPP's, focus lenses, vacuum windows, and debris shields. The average fluence is the maximum average fluence in the pulse including the effects of gain saturation and the radially-varying gain profile of the system. The peak fluence is taken as 1.78 times the maximum average fluence based on experience at LLE and elsewhere. Although FCC's have been upgraded to enhance broad-bandwidth frequency-conversion efficiency, there is nearly a 25% energy penalty for 1-THz operation.

Table 1.2-1
Energy Performance of OMEGA with a 1.0-ns Square Pulse

	No SSD bandwidth	1.0-THz SSD
Peak power of main pulse	31.2 TW	23.8 TW
UV energy on target (kJ)	31.2	23.8
UV energy after FCC (kJ)	35.2	27
Average fluence after FCC (J/cm^2)	1.13	0.87
Peak fluence after FCC (J/cm^2)	2.02	1.55
Conversion efficiency	70%	55%
IR energy before FCC (kJ)	50.4	50.4
IR avg. fluence before FCC (J/cm^2)	1.59	1.59
IR peak fluence before FCC (J/cm^2)	2.84	2.84

1.3 TOP-LEVEL CONFIGURATION

The OMEGA laser system is installed in the same facility that formerly housed the 24 beam OMEGA system. The most significant feature of the facility is the concrete box beam structure [67 m long, 29 m wide, and one story (4.9 m) high] that serves as an “optical table” on which the laser is built. This optical table rests on a bed of gravel and is structurally independent from the laboratory building enclosing it. As shown in Figure 1.3-0, the OMEGA laser system is installed on the optical table in two bays separated by a neutron-absorbing shield wall. The shield wall includes a viewing area called the “Visitors Gallery,” which looks into both bays. The western bay contains the IR laser components and is called the Laser Bay. The eastern bay is dominated by the target mirror structure (TMS) and target chamber (TC) and is called the Target Bay (TB). The Laser Bay and Target Bay are climate controlled and designed to operate as Class-1000 clean rooms, but actually perform to nearly Class-100 conditions. The area inside the facility below the Laser Bay contains the capacitor bays, which house the power conditioning system that powers the laser amplifiers. The Pulse Generation Room (PGR) is also below the Laser Bay. The area below the Target Bay, called LaCave, contains support systems for experimental diagnostics and the target insertion portion of the Cryogenic Target Handling System (CTHS). Supporting systems, such as the laser spatial filter vacuum piping, deionized (DI)/glycol cooling piping, and nitrogen gas piping, are also installed beneath the laser bay. The Control Room is located in the laboratory building just north of the Laser/Target Bays. The laboratory building also houses offices, laboratories, and supporting services.

Figure 1.3-1 is a schematic representation of the elements that make up the OMEGA system. Figure 1.3-2 illustrates the physical layout of the same elements. The laser drivers subsystem produces the shaped seed pulses and delivers them to the stage-A splitter in the Laser Bay. The remainder of the beam-handling equipment, up to the target itself, is referred to as the optomechanical subsystem. It includes the laser optical system and six power amplifier stages. These components amplify the pulses, divide them into 60 beams, and control arrival time at the target, energy, polarization, and spatial distribution of each beam. The optomechanical system also includes the frequency-conversion crystals, which triple the frequency of the IR beams to produce UV energy and target bay subsystems, which transport the beams to the target, and align and focus them precisely. The experimental system includes the target subsystems, which establish and maintain a vacuum within the target chamber and insert and position the targets, and the experimental diagnostic instruments that acquire data during shots.

The laser beams originate in the Oscillator Room off of the LLE lobby (not shown). The shaped pulses produced in the Oscillator Room are sent via optical fiber to the PGR, which is directly below the laser drivers area in the Laser Bay. The PGR is the facility where the laser beam is spatially formed and, in the case of the SSD driver, modified substantially to improve the on-target laser uniformity. The driver beams go through a periscope to the laser bay where they are distributed to three separate amplifier systems: the SSD, main, and backlighter large-aperture ring amplifiers (LARA). After amplification in the LARA, each beam is spatially filtered and propagates westward into the stage-A beam splitter. As is detailed in the next section, these three sources can be configured to produce a variety of target irradiation conditions. Only the basic, single-driver configuration is described here.

The single driver beam is split three ways at the A-split. All of the beam splitters are configured with polarization-control wave plates that provide the ability to accurately control the energy balance between beams. After the A-split, each beam is amplified and split five ways (B-split), resulting in 15 beams. These beams, now at 1/5 the output energy of the A amplifiers, are amplified again. The stage-A and stage-B amplifiers are 64-mm rod amplifiers. The 15 beams are then expanded and propagated through 90-mm amplifiers (stage C).

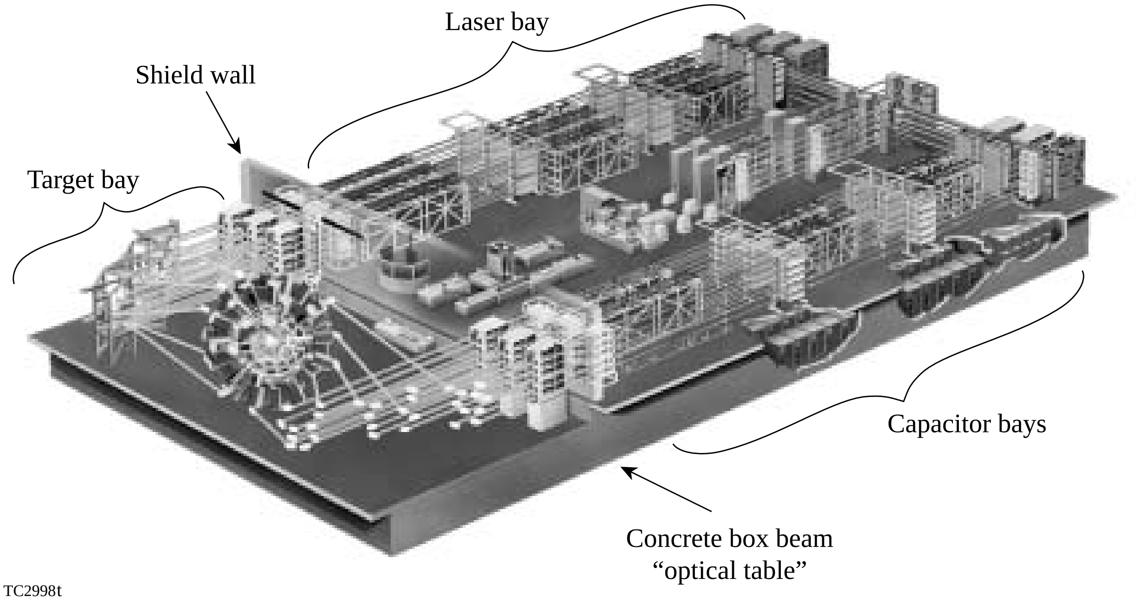


Figure 1.3-0
The OMEGA laser system is built on a concrete structure that is independent of the surrounding building.

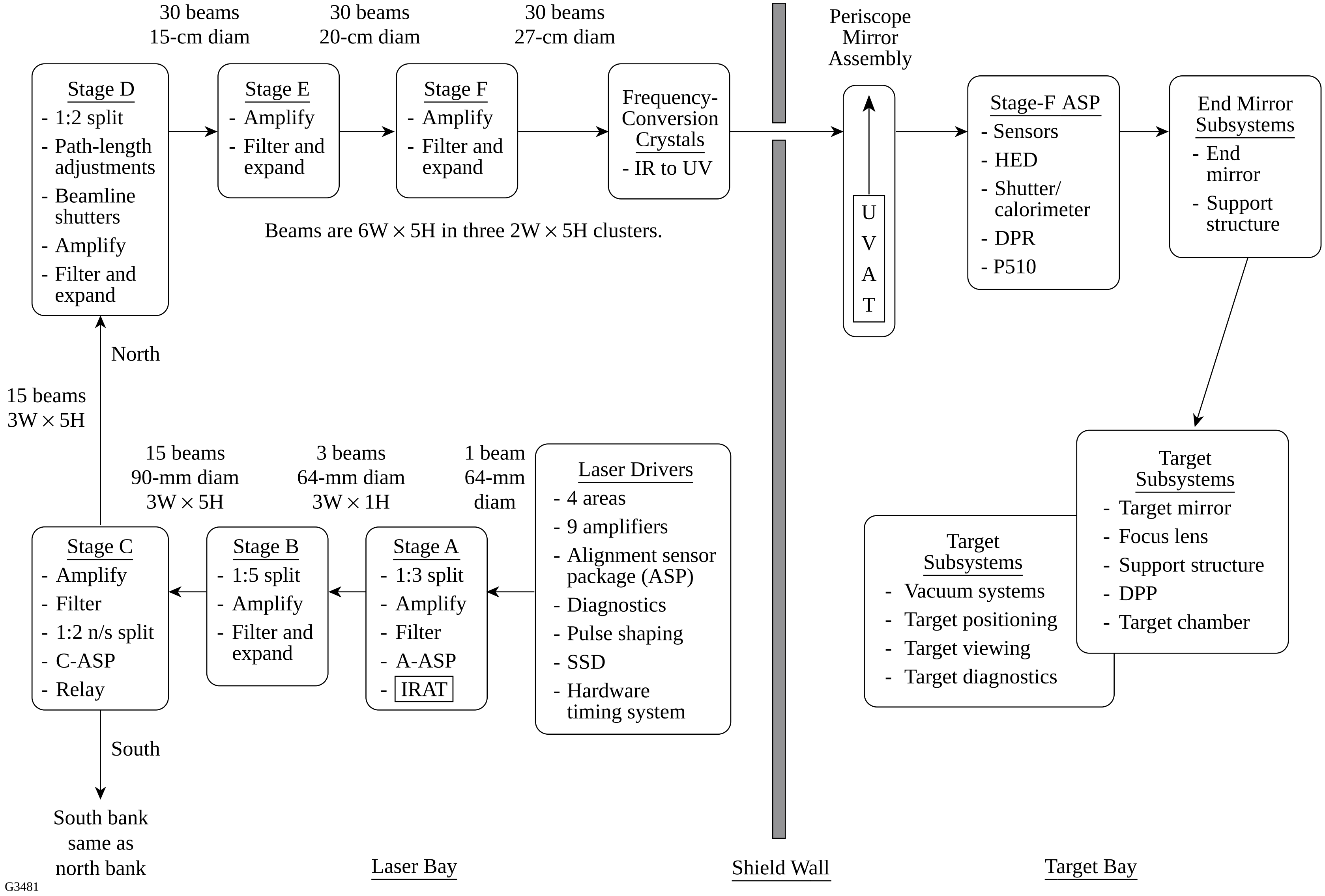


Figure 1.3-1
A schematic of OMEGA. IRAT and UVAT are the IR and UV alignment tables; ASP's are alignment sensor packages.

Each beam is then split four ways at the end of the bay. The resulting 60 beams pass through assemblies that permit path-length adjustment needed to compensate for unavoidable differences in transport paths to the target chamber or to provide precision beam-timing delay for experiments. This adjustment allows control of individual beam arrival times to ~10 ps. A range of travel of 9 ns available on each beam permits intentional mistiming of beams for special experimental configurations.

The 60 beams then propagate eastward, back down the length of the laser bay, 30 beams on the north side and 30 beams on the south side of the Laser Bay. The beams are arrayed in six clusters of ten beams (two wide, five high). Each beam passes through a second 90-mm rod amplifier (stage D) before being amplified by the stages-E and -F disk amplifiers. (These feature clear-aperture diameters of 150 mm and 200 mm, respectively.) Both the 64-mm and 90-mm rod amplifiers are modified versions of the original OMEGA amplifiers and are pumped by 12 longitudinal flashlamps along the barrel of the rod. In the disk amplifiers, the laser gain media is a face-pumped disk geometry because rod amplifiers are not feasible at the larger apertures. The disk amplifiers are termed single-segment amplifiers or SSA’s because each amplifier is dedicated to a single beam. The disk amplifiers were designed and prototyped at LLE prior to deployment on OMEGA; their performance is described in Chap. 3.

The 30 beams propagating toward the Target Bay on each side of the Laser Bay are all mutually parallel but are angled 0.75° toward the center of the Laser Bay. This angle is required to map the 60 beams onto the spherical target chamber using only two mirrors per beam while limiting the incident angle on the mirrors to 60° or less. Additional advantages of this wedged configuration are that it

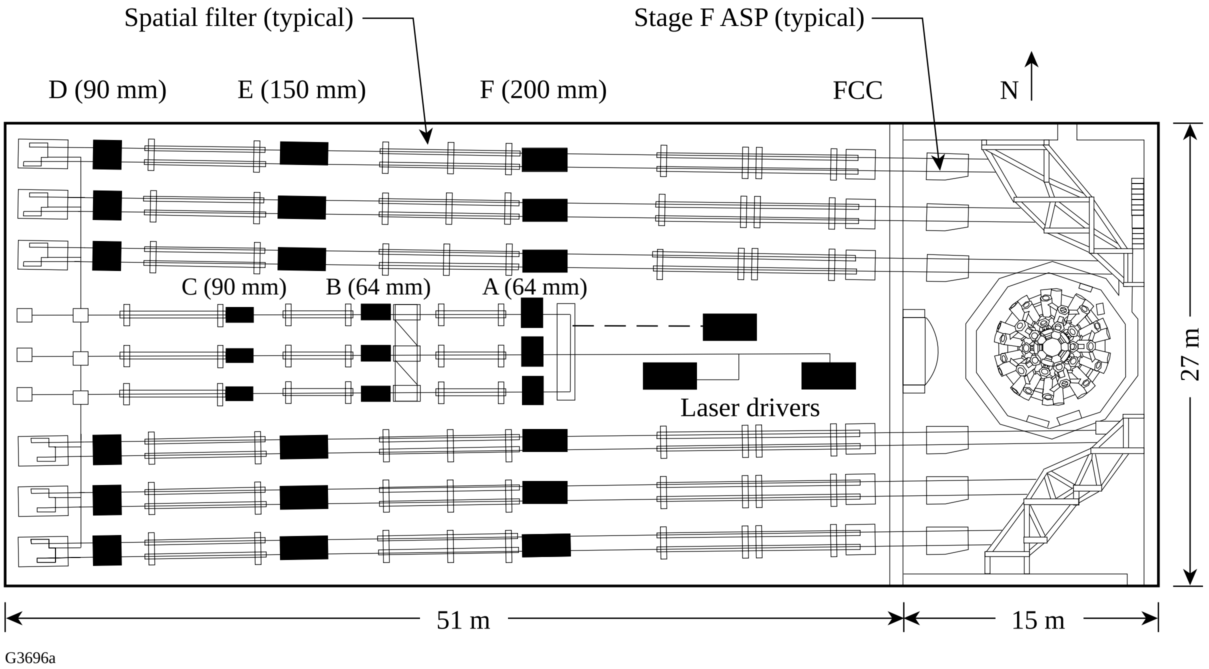


Figure 1.3-2
The physical layout of OMEGA. The location of four stages of rod amplifiers (A–D), two stages of disk amplifiers (E, F), and the frequency-conversion crystals (FCC’s) are indicated.

minimizes the in-air path length of the UV transport system to a total of 18 meters propagation in air. Minimization of in-air path length is required to stay below the thresholds where stimulated rotational Raman scattering (SRRS) will occur. SRRS is a phenomenon that can degrade the performance of the system and/or damage transport optics.

At each stage of the laser, spatial filtering is used to remove high-spatial-frequency noise in the beam and to ensure correct image relaying. Image relaying is critical to the performance of laser beams with SSD because it prevents excessive excursions of different frequencies across the beam aperture. Spatial filtering mitigates the beam degradation that would otherwise result from the frequency-dependent, grating-induced differences in propagation directions. Image relaying and spatial filtering also prevent intensity modulation caused by interference effects and nonlinear, intensity-dependent phase errors.

The final amplifier outputs are spatially filtered and magnified a final time. They then propagate through thin-film polarizers before reaching the FCC’s. The polarizers maximize conversion efficiency by ensuring that the correct linear polarization is incident upon the crystals. UV light reflected from the target is prevented from propagating backward through the laser system by a UV-absorbing window on the input of the frequency-conversion cells. Frequency conversion to the third harmonic (351 nm) is carried out using the polarization-mismatch method developed at LLE. After frequency conversion, the beams pass through holes in the 76-cm-thick concrete shield wall and enter the Target Bay.

Each beam has a unique identification; the 15 beams propagating west are referred to as “legs.” The 60 beams that emerge from the stage-D splitter are called “beams.” Figure 1.3-3 shows the OMEGA beam-numbering convention.

In the Target Bay, each beam encounters a stage-F alignment sensor package (F-ASP), which provides the alignment reference for the laser beamlines. The F-ASP’s are housed in six structures constructed of a cast epoxy/granite composite. These massive structures (20,000 kg each) ensure the thermal and vibrational stability necessary for the required ~1-μrad system-alignment accuracy. Also in these structures are optical pickoffs that distribute a fraction of the beam energy to the alignment, energy, and pulse-shape diagnostics.

The F-ASP’s provide the reference to which IR and UV beams are aligned. Both IR and UV alignment beams are referenced to the same position on the F-ASP camera. The periscope mirror assembly (PMA) is a moving gantry system that can insert a full-aperture UV beam from the UV alignment table (UVAT) into any of the 60 beamlines aligned to the F-ASP camera.

The F-ASP’s also provide a sample of each beam via fiber optic to the harmonic energy detector (HED) and to the P510 UV streak camera system. The HED system consists of integrating spheres that capture and measure a small fraction of the laser beam energies at the fundamental (1054-nm), second (527-nm), and third (351-nm) harmonics produced by the FCC’s. HED diagnostic data is the primary laser-energy diagnostic for OMEGA. The P510 cameras can measure the temporal pulse shape of all ten beams from each cluster. Comparisons between beam-intensity profiles are used to characterize the power balance and infer the time instantaneous target irradiation uniformity.

In the Target Bay, the linear geometry of the laser transitions to the spherical geometry of the target chamber. Each beam is transported to the target chamber via two mirrors: the end mirror on the beam axis and the target mirror on the target mirror structure (TMS). The focus lens assembly (FLAS), which holds the focus lens and the DPP for each beam, is mounted on the chamber. The focused beam enters the evacuated target chamber through a flat blast window assembly (BWA), which has two optics, a vacuum window, and a thin debris shield. The TMS supports the target mirrors, the target chamber, and its ancillary systems and is surrounded by the TMS platform for personnel access. These are shown in Fig. 1.3-4 and will be further described in Chaps. 5, 6, and 7.

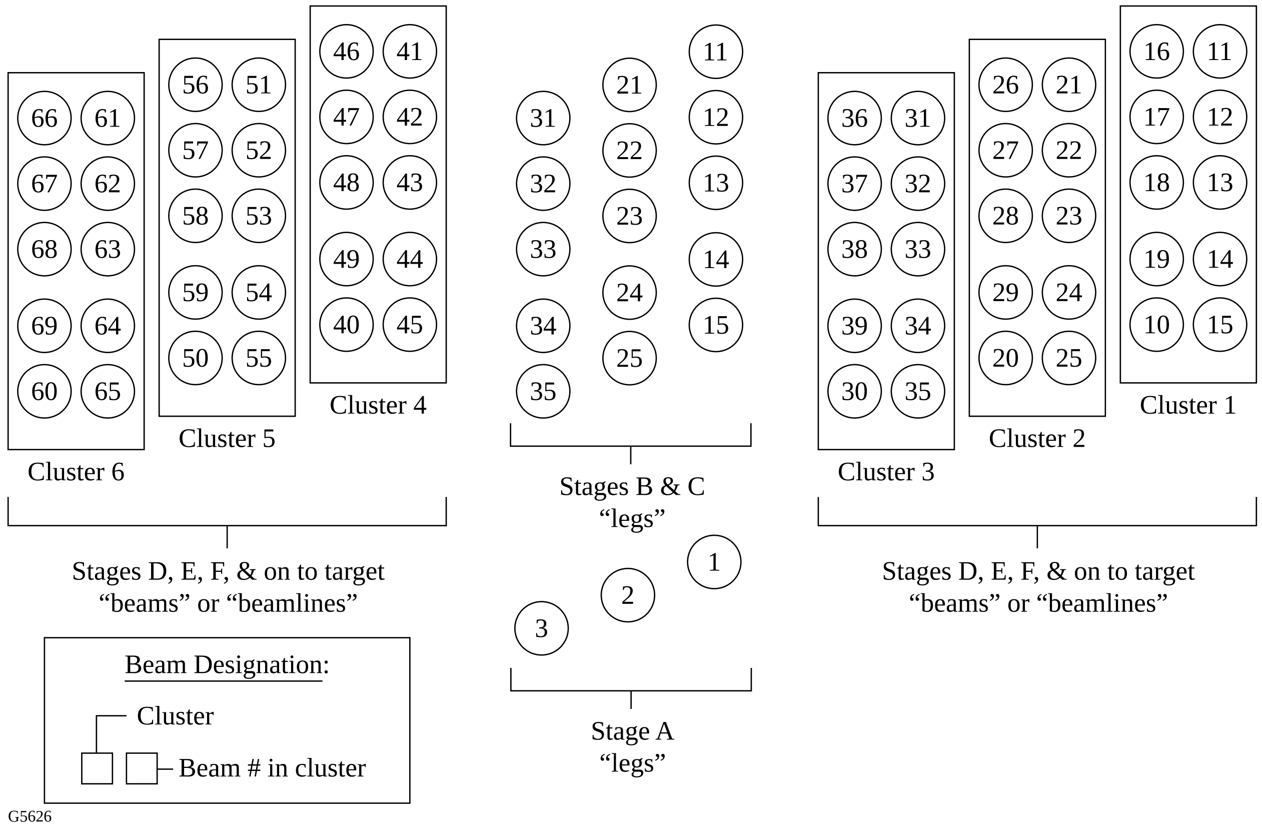


Figure 1.3-3
OMEGA beam designations as viewed from the Target Bay.

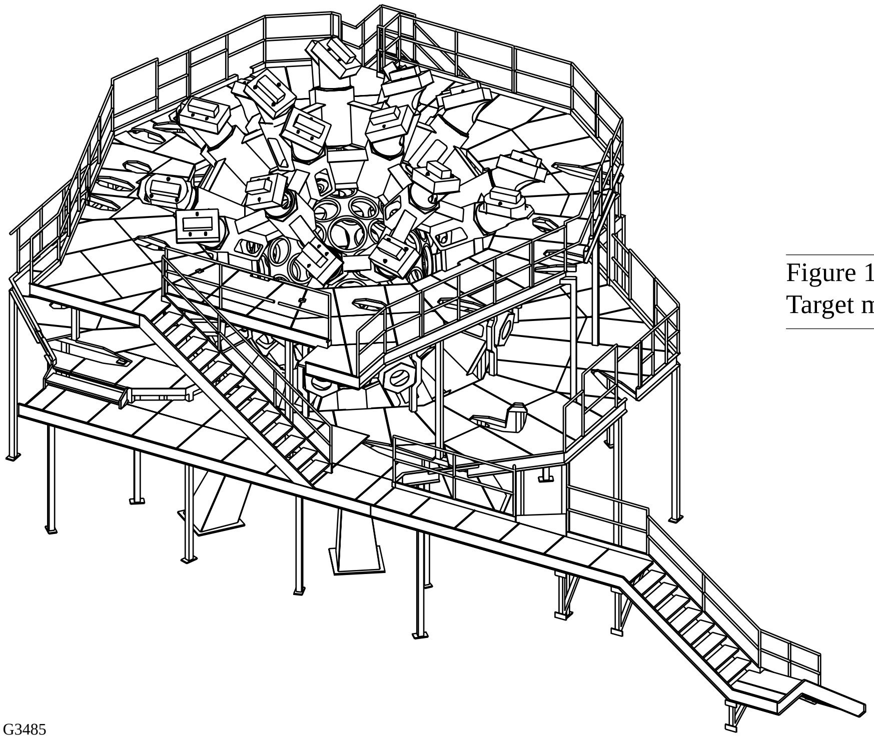


Figure 1.3-4
Target mirror structure and personnel platform.

1.4 LASER-DRIVERS SUBSYSTEM

The laser drivers subsystem consists of the equipment that provides the temporally shaped seed pulses to the beamlines subsystem and a “fiducial” pulse train that provides a timing reference for many of the laser and target diagnostics. The precision electronic timing system, called the Hardware Timing System (HTS), that is used to trigger time-critical functions throughout the OMEGA system is also part of the laser drivers subsystem.

The three separate seed pulse drivers are called the main, the SSD, and the backlighter. The subsystem is configured so that either the main or the SSD driver can be injected into the stage-A splitter, where it would normally continue on to feed each of the three stage-A legs and all 60 beamlines. The backlighter driver can be injected into any one of the stage-A legs, where it can feed 20 beamlines. When this is done, the main or the SSD driver can feed the other two stage-A legs and the remaining 40 beams.

The names applied to the three driver systems that can seed OMEGA are explained below:

- The “main” driver is the most streamlined source. It has all of the basic necessities for generating a round beam of the appropriate pulse shape and timing needed for shots. It does not include the SSD feature needed for advanced beam smoothing on target and, therefore, is generally of greater utility to indirect-drive experiments.

- The “SSD” driver is similar to the main driver but has additional equipment to smooth the profile of the beam on target. The SSD smoothing is accomplished by more than 100 components including electro-optical modulators and in-house-fabricated holographic diffraction gratings. Because the SSD modulation effect can be quickly applied to or removed from the pulses provided by this line, the SSD driver has become the primary source for OMEGA.

- The “backlighter” driver equipment is so named because its intended primary use is to seed beams that may be pointed at separate target elements used to produce x rays that backlight the primary target for diagnostic purposes. Because this line does not have an amplifier after its LARA, it is capable of seeding only one 20-beam OMEGA leg. When the backlighter driver is injected into an OMEGA leg, the resulting 20 beams may be directed to all of the same target or diagnostic destinations as beams that are seeded by the other two drivers. This line has no SSD capability.

The laser-driver subsystems, outlined in Fig. 1.4-1, are located in the Oscillator Room (OR), the PGR, and the driver line area of the Laser Bay. In addition, a laser driver system in the Target Bay is used to generate a timing reference (“fiducial”) pulse for diagnostic systems. This fiducial laser is a LARA similar to that in the SSD, main, and backlighter drivers, but it produces a comb of pulses. This independent but synchronous laser provides IR, green, and deep UV pulses to instruments located throughout the laser facility.

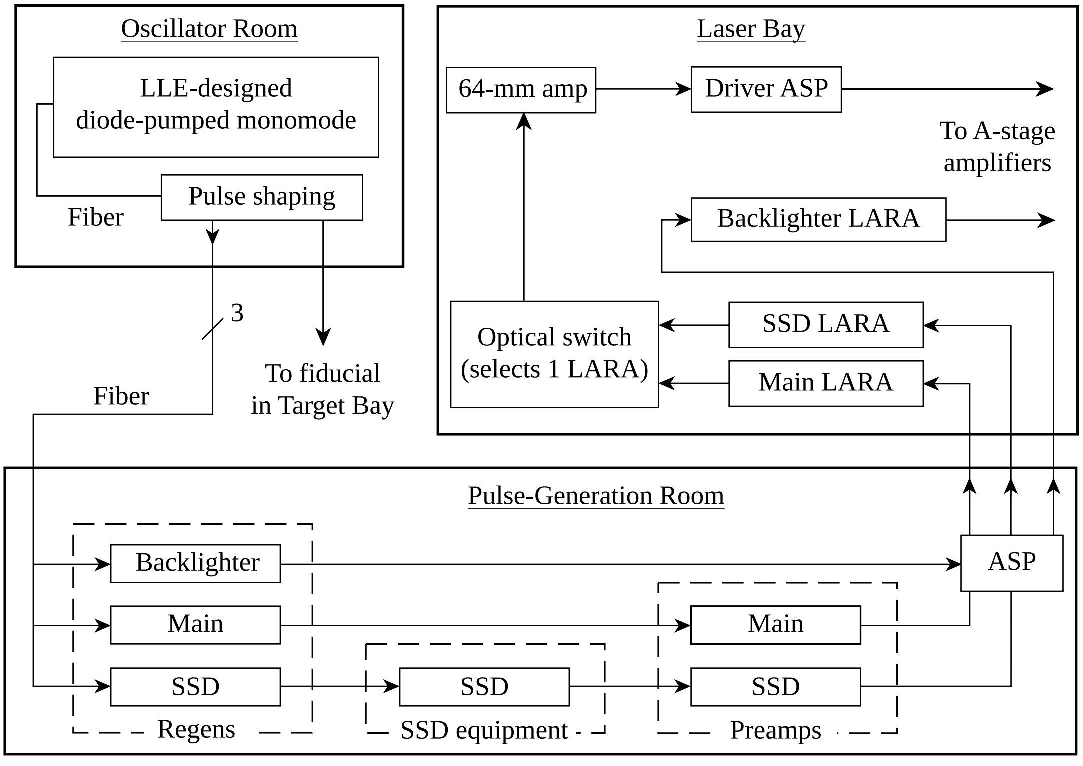


Figure 1.4-1
A block diagram of the laser-driver subsystem. The equipment is located in four areas: Oscillator Room, Pulse-Generation Room, the Laser Bay, and the Target Bay.

The optical pulses used in the OMEGA system originate in the OR, where a master oscillator produces 80-ps pulses at a rate of ~76 MHz. The OR is approximately 20 m from the PGR and is fiber optically coupled to the PGR. Fiber optics are used throughout the OR for flexibility and alignment insensitivity. The physical separation of the OR and PGR is intended to allow for flexible pulse shaping without impacting the performance or reliability of the PGR subsystems.

The PGR is located below the Laser Bay and is the home of several major elements of the driver line, including pulse selection, regenerative amplification, pulse truncation, driver diagnostics, amplification, beam smoothing (the electro-optic frequency modulation and pre-delay components of SSD), and alignment. As shown in Fig. 1.4-1, the main, SSD, and backlighter regenerative amplifiers are seeded by pulses from the OR. The regenerative amplifiers (regens) increase the energy of the ~1.0-nJ input pulses to 0.1 mJ, using ~100 round-trips in a laser cavity. Various diagnostics measure the energy, timing, alignment, and stability of the regens.

Beyond the regenerative amplifiers, the pulses in the SSD line encounter the electro-optic modulators and gratings required for SSD. These systems impress the bandwidth and pre-delay required for high irradiation uniformity on target.

To decouple the sensitive PGR optical configuration from heat and electromagnetic interference (EMI) sources, much of the associated electronic equipment is housed in an adjacent room. The various timing circuits, regen cooling system, and majority of the PGR power supplies are located in this room.

The 0.1-mJ outputs from each regen are separately directed upward, via a vertically mounted periscope, to the next set of amplifiers, which is located on the Laser Bay level. These amplifiers are 40-mm, large-aperture ring amplifiers (LARA’s). One is provided for each of the main, SSD, and backlighter pulses. Each LARA provides a gain of about 10,000 in four round-trips.

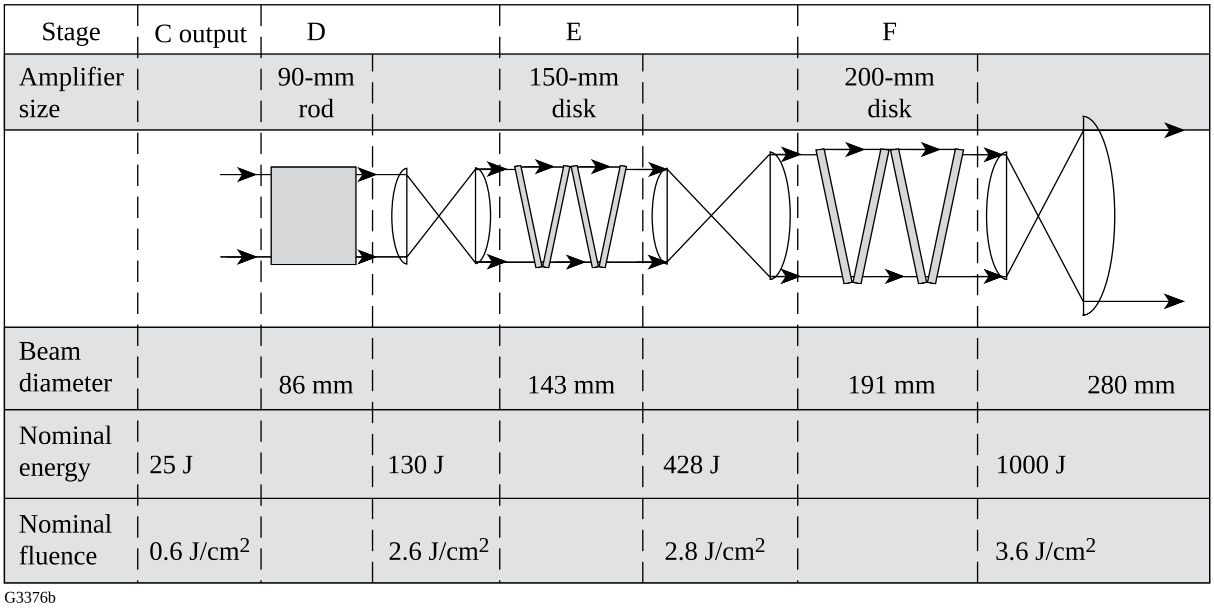
Either the SSD or main driver is selected by the position of a kinematic mirror for propagation to OMEGA. Prior to leaving the driver area, the selected driver (main or SSD) is amplified to 4.5 J by a 64-mm rod amplifier. The pulse is then spatially filtered and propagated to the stage-A beam splitter, where the driver-line pulses are split three-ways and injected into the OMEGA power amplifiers.

The backlighter driver generates a 1.5 J laser pulse capable of driving one of the three legs from the A-split in lieu of the main or SSD driver pulses. The backlighter pulse arrives at the stage-A splitter by a path that is separate from that used by the other two drivers.

1.5 AMPLIFIER STAGING

The power amplifier section of OMEGA has a 64-mm input aperture and a 20-cm output aperture. The output aperture of the final amplifier was initially determined by the number of beams, the total energy requirement, and damage thresholds for the optical coatings. The amplifier staging comprises four stages of rod amplifiers (A–D) and two stages of disk amplifiers (E and F), all separated by spatial filters. Figure 1.5-1 provides the details of the final stages. The final aperture of the beam is increased to 28 cm to reduce the fluence on the UV transport optics.

A total of 93 rod amplifiers are used in stages A–D. The rod amplifier design evolved from the original OMEGA system and incorporates significant mechanical and thermal improvements. Rod amplifiers use de-ionized water cooling for the flashlamps and feature a separate DI/glycol cooling



Stage	C output	D		E		F	
Amplifier size		90-mm rod		150-mm disk		200-mm disk	
Beam diameter		86 mm		143 mm		191 mm	280 mm
Nominal energy	25 J		130 J		428 J		1000 J
Nominal fluence	0.6 J/cm^2		2.6 J/cm^2		2.8 J/cm^2		3.6 J/cm^2

Figure 1.5-1
The amplifier staging of the OMEGA laser consists of four stages of rod amplifiers and two stages of disk amplifiers. The early stages compensate for the 1:60 splitting; the last three stages (shown here) provide ~97% of the beamline energy.

channel along the barrel of the rod. The disk amplifiers for the last two stages are of a new design utilizing conventional box geometry with a 15-cm aperture at stage E followed by a 20-cm aperture at stage F. Each amplifier contains four Nd:glass laser disks. The clear aperture of the final amplifier is set by damage constraints; specifically, the antireflection coating on the input lens of the final spatial filter will damage if the laser pulse reaches 9.8 J/cm^2. The 15-cm stage provides a small signal gain of 4.2:1, and the 20-cm stage a gain of 3.0:1.

The disk amplifiers, like the rod amplifiers, use water-cooled flash lamps that facilitate operation at a high storage efficiency. The benefits of this are outlined in Chap. 3. Both the 15- and 20-cm amplifier stages utilize the same power-conditioning and pulse-forming network (PFN). The cooling times for the disk amplifiers permit a 1-h shot cycle. The modular nature of the design allows for the rapid change of flash-lamp pump modules within this shot cycle.

1.6 FREQUENCY CONVERSION AND UV TRANSPORT

Conversion of the 1054-nm IR energy produced by the laser amplifiers into the 351-nm UV energy that is delivered to the target is achieved in the frequency-conversion crystal (FCC) subsystem, located in the Laser Bay at the end of each cluster just before the shield wall. Each of the 60 FCC assemblies has an input polarizer and a cell assembly that includes three crystal optics made from potassium dihydrogen phosphate (KDP) and a UV absorption window. With the correct combination of polarization angle, crystal axis orientation, and crystal temperature, the first KDP crystal, called the "doubler," doubles the frequency of part of the incoming 1054-nm beam. The second crystal, called the "tripler," combines the resulting green photons with the remaining IR photons to efficiently produce UV photons. A second "tripling" crystal provides a capability for efficiently converting terahertz (THz) SSD bandwidth. The gimbal mount that holds the crystal assembly is provided with a three-axis motorized positioner. The temperature of each FCC is kept stable by an insulated enclosure and is sensed to allow for angular tuning of the gimbal axes in response to minor changes in temperature. The temperature tuning is achieved through the computer control system and provides for maximum efficiency of frequency conversion.

After the IR beam is converted to the UV by the FCC's in the Laser Bay, it passes through the shield wall and through the Stage F-ASP. The UV transport system utilizes two mirrors (an end mirror and a target mirror) per beam to direct the UV beam exiting the F-ASP to the target chamber. The beams are focused onto the target using 1.8-m-focal-length, *f*/6.7, fused-silica aspheric lenses. These lenses are mounted in precision mounts that allow accurate control of the lens position for focusing. This subsystem is called the focus lens adjustment system or FLAS. A distributed phase plate (DPP) can be mounted on the input end of the FLAS. The DPP optics create a uniform, repeatable spot approximately the size of a typical fusion capsule. Because some experiment campaigns do not irradiate spherical capsules, these optics are removable. Different designs are available to create different irradiation conditions.

The F-ASP's and periscope mirror assembly (PMA) are located along the shield wall, and the north and south ends of the Target Bay are filled with the end-mirror structures (EMS). A personnel platform surrounds the target mirror structure (TMS) and provides three working levels, allowing access to all of the ports on the target chamber, as well as the transport optics. The north EMS platform supports the fiducial laser, and a laser diagnostic station has been deployed on the south EMS platform.

Central to the target area is the TMS, which supports the target mirrors and target chamber. The 3.3-m-diam chamber is the heart of the experimental system, where targets are irradiated and the various diagnostics are supported. The diagnostic suite has both fixed and flexible diagnostic platforms. Fixed diagnostics include plasma calorimeters that measure absorbed laser energy, x-ray pinhole cameras that capture time-integrated images of the target emission, Kirkpatrick–Baez (KB) microscopes, and x-ray and neutron streak cameras that record time-resolved target events.

Flexible accommodations for experimental diagnostics are provided by ten-inch manipulators (TIM's). Six of these subsystems are currently installed on the target chamber. Each provides mechanical, vacuum, and electrical/control support and positioning for any compatible instrument that needs to be positioned near the center of the target chamber. Also installed on the chamber are the target viewing systems, the system used to position ambient temperature targets, the upper and lower pylon elements of the Cryogenic Target Handling System, and the cryogenic pumps used to create the high vacuum environment.

1.7 OPTICAL ALIGNMENT

Because the high-energy pulsed beam is converted from IR to UV part way through the OMEGA system, the OMEGA alignment system must include both IR and UV sources. A hand-off between the two alignment sources takes place at the 60 F-ASP's. These utilize achromatic optics so that they can function at both wavelengths and are located in the Target Bay just prior to the end mirrors. Each F-ASP includes a special full-aperture pick-off optic that reflects 4% of the beam energy into the diagnostic subsystem while allowing the remainder to propagate onward to the end mirror. During the alignment process, a 4% sample of the alignment beam being used is directed to the alignment sensor. On a shot, the 4% sample of the high-energy pulse is directed to beam performance diagnostics.

The IR portion of the OMEGA system is aligned using a 1054 nm Nd-doped yttrium lithium fluoride (Nd:YLF) laser that is located on the infrared alignment table (IRAT) and is injected into the system at the A-Splitter. The beam train is aligned in a progression towards the target using a sensor package the A-Splitter, 15 sensor packages at stage C, and ending at pointing references in each of the 60 F-ASP's.

The UV portion of the system is aligned using a 351 nm cw laser that is mounted on the UV alignment table (UVAT) on the centerline of the system near the west wall of the Target Bay. The UVAT optics project separate full-aperture alignment beams northward and southward from the table into corresponding periscope mirror assemblies (PMA's). Each PMA functions to position movable mirrors at specific locations on the shield wall. These mirrors inject the alignment beam into one beamline at a time one each side of the bay.

Co-alignment of the IR and UV alignment beams in each beamline is achieved by steering the PMA mirrors to point the UV alignment beam to the pointing reference in the F-ASP. The portion of the UV alignment beam that passes through the pick-off optic is then steered to the target by moving the transport mirrors. The UV reflections from a surrogate target are transmitted back to an alignment sensor package on the UVAT to guide this process. The north/ south symmetry allows one north side and one south side beam to be aligned simultaneously.

1.8 LASER DIAGNOSTICS

Beam-energy measurements are required at various points in the laser chain. The most important measurement is made just after the FCC's, where a second-order Fresnel reflection from two uncoated optical surfaces transports 0.16% of the beam energy into a harmonic energy diagnostic (HED) package. The first uncoated surface is the primary pickoff that passes 96% of the energy to the target. The second is on a flip-in optic that directs 4% of the first 4% to an integrating sphere via an evacuated optical relay. The optical layout ensures that the beam image plane is relayed to the rear surface of an integrating sphere. A fiber optic pickup in each sphere transfers the light to a spectrometer coupled to an optical multichannel analyzer (OMA). There is one spectrometer/OMA unit for the 30 beams on each of the north and south sides of the Target Bay. The HED spectrometers are calibrated using 60 full-aperture calorimeters that can be inserted into the beam to measure its total energy. These calorimeters are of a conventional absorber/thermopile design.

The UV delivered to target is equal to the energy measured by the HED multiplied by the passive transmission of the UV transport optics. Each beam has two UV high-reflector mirrors, a distributed phase plate, a focus lens, a vacuum window, and a debris shield. An instrument called the OMEGA Transport Instrumentation System (OTIS) measures the cumulative transmission of the ten optical surfaces and four substrates. OTIS consists of a CCD-based ratiometer embedded in the UVAT and special reflective sphere inserted into the target chamber. This system is capable of characterizing the UV transport with better than 1% precision.

An instrument called the P510 streak camera measures temporal pulse shapes of the output of each of the 60 beams. The instrument system consists of six separate instruments, each of which measures the ten beams from a cluster. These cameras have very high temporal bandwidth for a high-fidelity time history of the irradiation on target. Because the UV shape on target is one of the critical parameters that an investigator conducting experiments on OMEGA is interested in, this system is calibrated frequently for optimal performance.

1.9 CONTROL SYSTEM

The OMEGA control system provides the system operators with remote control of subsystems, displays of sensor data, and safe sequencing of key processes. The control system also collects and records information about each shot. Operator interfaces are provided in the Control Room and throughout the facility.

Functional Subsystems

The control system architecture reflects the hierarchical subsystem configuration of OMEGA. Four autonomous consoles in the Control Room allow each subsystem to be operated by the respective trained operators. During shot operations, the subsystem functions are coordinated by a Shot Director who uses a fifth, supervisory, control station. Figure 1.9-1 illustrates this arrangement.

Communication between the operators and the supporting technicians is facilitated by a headset-based intercom and a facility public address system. This verbal communication is supplemented by messages that pass between the application programs running on the computers. High-level application-to-application communication uses a standardized OMEGA intercommunication protocol (OIP) that conveys limited system status and control information in both directions. Figure 1.9-2 shows two examples of the “generic executive” graphical user interface that portrays the status information to the operators. Specific versions of the generic executive are configured as the Shot Executive (SE), Laser

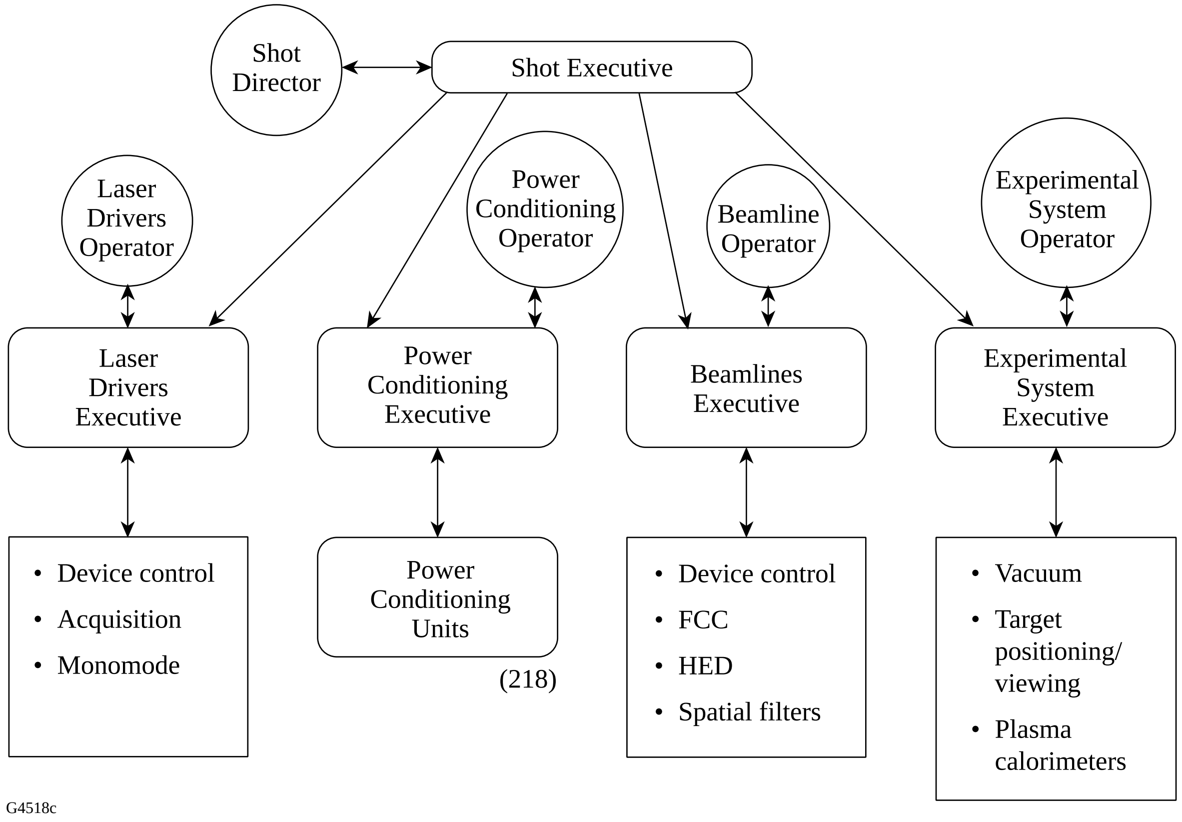


Figure 1.9-1
The top-level architecture of the OMEGA Control System. (Circles represent human operators; boxes represent applications running on computer workstations.) Three levels of computers are used to provide a system with appropriately distributed processing capabilities. Operators use executive and subsystem-specific applications to operate numerous microprocessor-controlled devices via local networks. The shot director monitors and coordinates the subsystem activities.

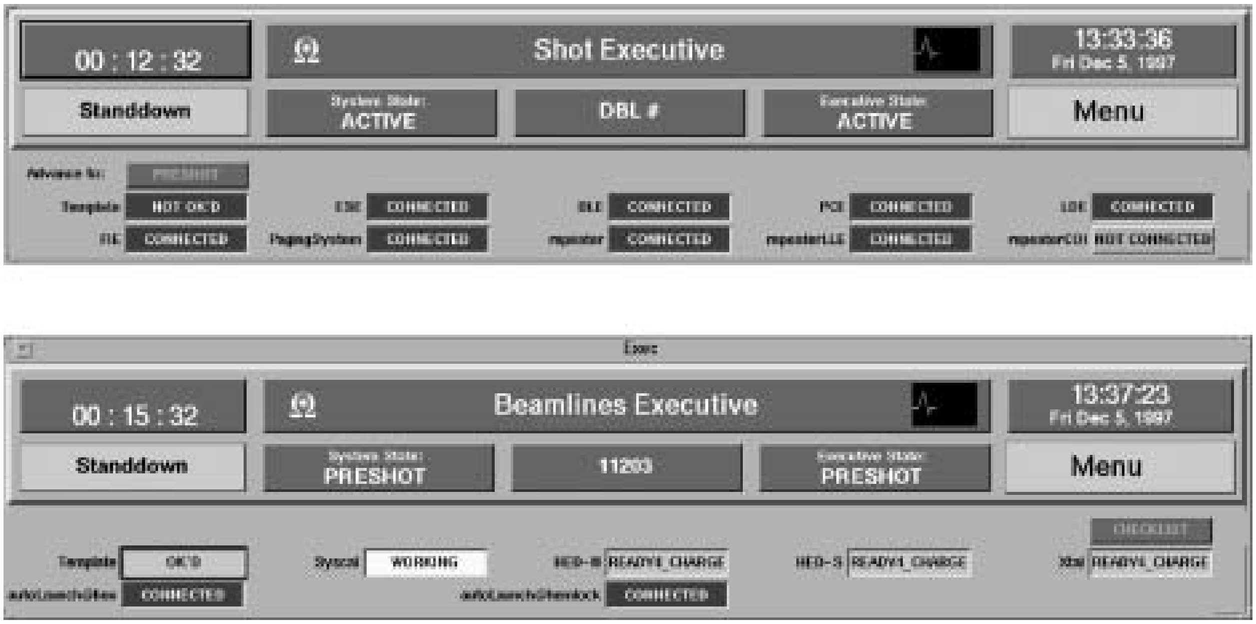


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Figure 1.9-2
Each Control Room operator is provided with a standardized display of the status of the overall OMEGA system and of the sub-tier processes critical to his or her functions. Two examples are shown here.

Drivers Executive, Beamlines Executive, and Experimental Executive. [Although the Power Conditioning Executive (PCE) is functionally similar, it is not based on the same generic code as the other executives. Yet another variation is the Facility Interlock Executive, which is used, primarily by the Shot Director, to manage room access and warnings.]

Each executive provides a top-level operator interface for the subsystem and controls and receives information from devices in the bays by communicating with one or more “intermediate” processors over bus extensions, the Ethernet, or other standard communication links. These intermediate computers serve to relieve the executive of routine computation and downward communication tasks. Each of the subsystem executives monitors the applications required for configuring and executing a shot at that console. All executive processors are synchronized to the shot sequence by the Shot Executive.

Control Room and Control Stations

The OMEGA Control Room, on the second floor of the laboratory building, is the focus of operations. Figure 1.9-3 is a layout of the Control Room that shows the space allocations for control, operations, and planning and data analysis activities. The equipment is arranged to allow the operators to work together and to minimize distractions.

Shots and System States

The control system facilitates the operational activities that maintain the system, prepare it for a shot, execute the shot, and record the shot results. Computer network communication is used to coordinate actions requiring synchronization to within about one second. The precision timing required to execute and diagnose a shot is provided by the hardware timing system (HTS). A “handoff” between the two levels of timing control takes place 20 seconds before a shot is triggered.

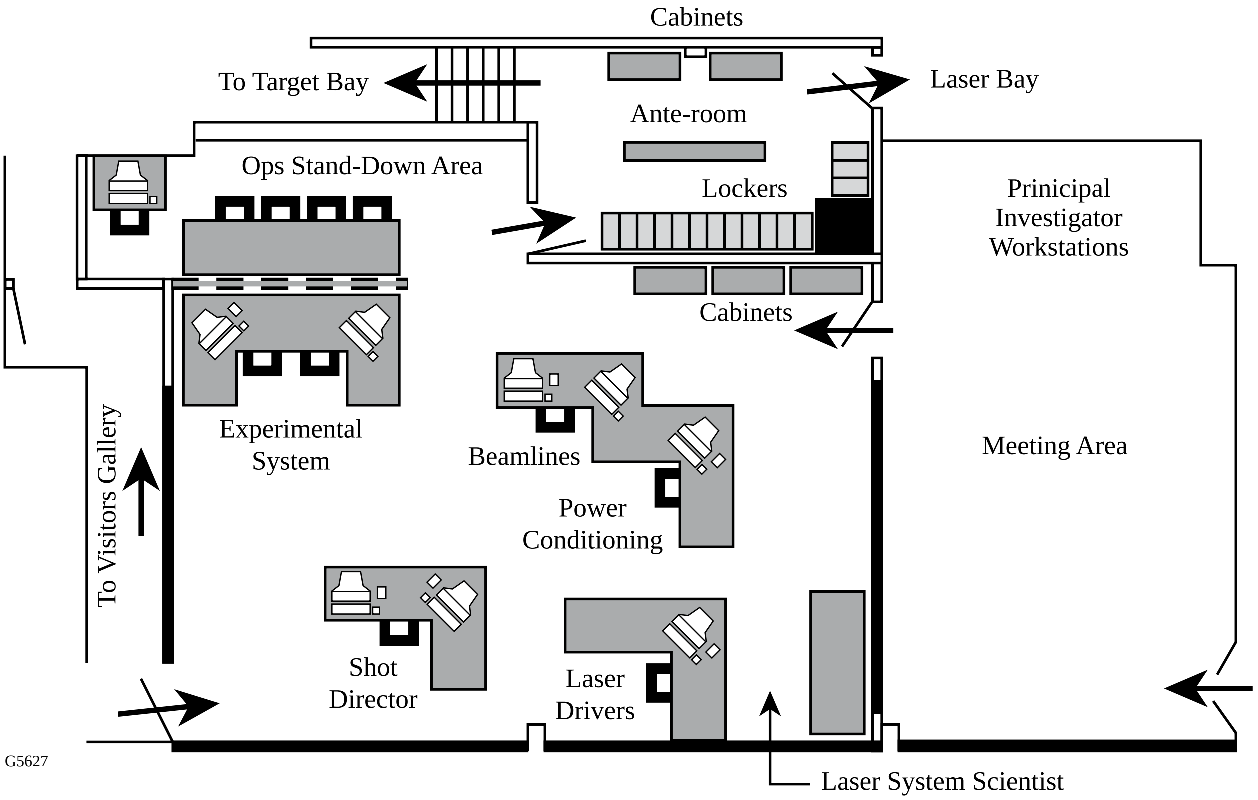
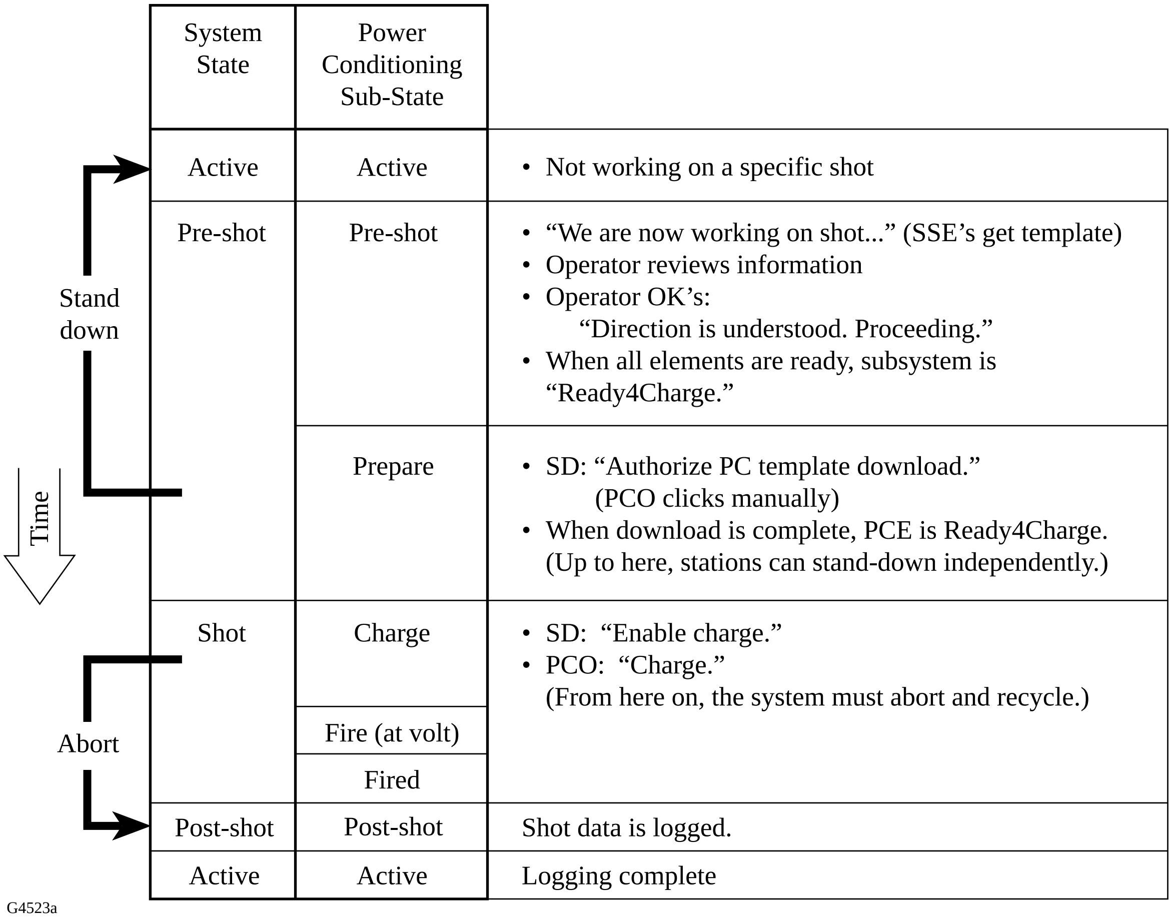


Figure 1.9-3
The five Control Room workstations are arranged to allow the operators to work together with minimal distraction. A separate conference room is used for briefings, data assessment, and planning. The Target and Laser Bays are accessed through the Control Room.

The approach to system operations makes use of the concept of a “shot cycle,” consisting of a sequence of “system states” and a number of distinct “shot types.” The system states partition the activities into known situations for communications and coordination. The shot types identify the extent to which the high-energy pulsed beam is propagated and the degree of system-wide coordination that is required.

Figure 1.9-4 illustrates the system state sequence that is executed for every type of shot. In the “active” state, the system is not formally preparing for a specific shot and the subsystems are operated independently for maintenance or setup. Formal preparations for a shot are initiated by the Shot Director (SD) who uses the Shot Executive (SE) to specify a shot type and other key parameters and to communicate them to the other operators via the subsystem executives. The act of transmitting this “master template” information marks the transition of the system from the active state to the “pre-shot” state. The SE also transmits a “shot number,” which is the index to be used when the data from the intended shot is logged. Each subsystem operator reviews the setup information, signals approval to the SD, and proceeds to prepare for the shot.

When a subsystem has been readied, the operator signals the SD using a “checklist” button on the executive GUI. The SD then reviews key details of the setup with the operator before signifying concurrence on the Shot Executive. In the special case of the power conditioning subsystem, this process consists of the SD reviewing and approving the power conditioning “template” that details the online/



System State	Power Conditioning Sub-State	
Active	Active	• Not working on a specific shot
Pre-shot	Pre-shot	• “We are now working on shot...” (SSE’s get template) • Operator reviews information • Operator OK’s: “Direction is understood. Proceeding.” • When all elements are ready, subsystem is “Ready4Charge.”
	Prepare	• SD: “Authorize PC template download.” (PCO clicks manually) • When download is complete, PCE is Ready4Charge. (Up to here, stations can stand-down independently.)
Shot	Charge	• SD: “Enable charge.” • PCO: “Charge.” (From here on, the system must abort and recycle.)
	Fire (at volt)	
	Fired	
Post-shot	Post-shot	Shot data is logged.
Active	Active	Logging complete

Figure 1.9-4
The OMEGA shot cycle is a sequence of system states. In the “active” state, the system is not formally preparing for a specific shot and the subsystems are operated independently for maintenance or setup. The pre-shot/shot/post-shot sequence is repeated for each shot attempt. The power conditioning subsystem has sub-states.

offline status of the power conditioning units (PCU’s) and the voltage commands that will be sent to them for the shot. When this critical safety check is complete, the SD authorizes the transmission (“download”) of the template values.

When all necessary subsystems are ready for the shot, the SD authorizes the power conditioning operator to charge the PCU’s. This marks the transition from the pre-shot state to the “shot” system state. Within the shot system state, the power conditioning subsystem has sub-states that are not reflected in the other processes. These track the major steps of the power conditioning subsystem sequence. Once the charge command has been issued, the power conditioning subsystem controls the laser system to within ten seconds of the shot and then enables the key system elements to proceed on the basis of electrical master timing signals from the HTS.

The events synchronized by network messages include activation of high-voltage diagnostic power supplies, acquisition of background data, and “arming” elements so that they will respond to hardware triggers. The events synchronized by the hardware timing signals include selection of the optical pulses in the laser-drivers subsystem, triggering the electrical discharges that drive the flash lamps in the laser amplifiers, and the operation of diagnostic instruments.

Once the software and hardware sequencing has proceeded through the issuing of the shot triggers, the system enters the "post shot" state and each of the system elements that has acquired shot-related data proceeds to log that data to the system database. As the logging is completed, each element effectively reverts to its "active" state. When all of the elements have completed this process, the system is formally in the active state and ready to initiate another shot cycle.

Stand-down and Abort

The shot cycle can be interrupted by either a "stand-down" or an "abort." If a problem arises or a change of plans occurs prior to the system entering the "shot state" (the PCU's have not started to charge), the system can "stand down" to the active state. When the situation is cleared up, a new shot cycle can be initiated. Each subsystem can also stand down independently. In this case, the system remains in the pre-shot state, and the subsystem will automatically advance into its pre-shot state as soon as it is ready to do so. Because a stand-down does not cause shot data to be logged, the "shot number" is not incremented.

If a critical problem arises after charging has started, the shot is normally stopped by the abort process: Each of the executive GUI's has an ABORT button that can be used to initiate the process by signaling the PCE to execute an abort. All of the other software elements are also notified so that they can respond as needed. When an abort is signaled, the PCE immediately prevents the HTS from issuing the critical triggers and issues commands that dump the energy in the capacitors in the PCU's. Power conditioning and other subsystems then log data and the system proceeds to the active state. In this case, the "shot number" is used and the next shot attempt will be associated with the next sequential number.

The Shot Director can also stop a shot by pressing a switch that is hard-wired to the electric power substation that powers the PCU's, shutting off all of its output. This, in turn, dumps the energy in the capacitors and renders the system safe, even if a software or communication failure has occurred.

While the software-based abort and the hard-wired dump are effective in stopping a shot up to within about one second before the shot trigger, some conditions that necessitate preventing a shot can be detected only in the area of 10 to 100 milliseconds before the shot trigger. These include the target moving or not being in the correct location near the center of the target chamber or an error in the removal of the shroud from a cryogenic target. A mechanism that spoils the seed pulse in the laser drivers subsystem is used to address these conditions. This "driver abort" is automatically initiated by computer logic associated with a target detection subsystem. The action is to interrupt the trigger for the regenerative amplifier in the driver. The pulse that then propagates to the power amplifiers is too low in energy to be amplified to normal levels in the remainder of the system. This prevents laser damage due to energy passing through the target chamber.

Shot Types

Not all shots on OMEGA are target shots used for physics research. Many are used for system preparation, checkout and evaluation, or laser technology research and development. This has made it necessary to consider categories, or types, of shots. The seven "shot types" that have been defined are:

Type	Description
1	driver only
2	non-propagating (no driver)
3	propagating to the stage-A splitter
4	propagating to the stage-D splitter
5	propagating to the stage-F alignment sensor package
6	target shot with low (or no) neutron yield
7	target shot with high neutron yield expected

The shot type establishes which of the executive processes must be involved in the shot, the location at which propagation stops, and which bays must be closed to access.

In addition, each of the seven may be simulated as a “trigger test” shot: the system-state sequence is executed as it would be for an actual shot and the HTS triggers are produced, but no PCU’s are charged and the seed pulse is not amplified beyond the driver regenerative amplifiers. The two variations are

- Null Template Trigger Test: No PCU’s are included in the Power Conditioning Template.

- Zero Volts Trigger Test: One or more PCU’s are included, but the charge voltages are set to zero.

It is also possible to produce the HTS triggers without executing the system-state sequence. This is called a “Timing Test.”

Shot Request Forms

Execution of effective and safe experimental shots requires complete and detailed specification of the facility configuration and laser-operating parameters, extensive advance planning, and many hours of system preparation prior to and during the actual shot day. The Shot Request Form (SRF) is the primary vehicle for recording and communicating the specifications for a shot. A separate SRF is used for each target shot. Supplemental tools and forms are also generally used in planning and communicating about the sequences of related shots that are referred to as “campaigns.”

The SRF is a database object that is created within the LLE computer system primarily via inputs made at a web-based SRF user interface. This interface consists of a series of pages or screens called “forms” that collect information of various types. The forms include

- General - PI’s, campaign identification, planned date, planned order, …
- Driver - pulse shape, SSD modulation, …
- Target – characteristics, unique identifier, …
- Beams – groups defined by energy, pointing, focus, …

Target diagnostics are specified via a hierarchical series of groupings and setup forms.

Each SRF is automatically assigned a unique, sequential, identifying number at the time it is created. Appropriate controls are applied to limit both read and write access to the records. Figure 1.9-5 illustrates some of the relationships between the SRF, the database, and OMEGA operations.

The SRF can be viewed or printed, in part or whole, to provide a standard format for review and implementation. On shot day, SRF data values are also accessed directly by the OMEGA Control System and used to assist the operators in preparing for and executing the shot. Once a SRF has been used to specify a system shot, it is considered expended and will not be reused. The SRF data values are retained indefinitely. The SRF values, indexed by the unique identifying number, may be retrieved for use in data assessment and can be copied to create new SRF's.

Data Acquisition and Archiving

Both system configuration and diagnostic sensor data are logged for each shot. The system configuration data consists of all of the parameters that are sensed by the computer system and all of the parameters that can be altered by inputs to the software. Diagnostic data is generally stored locally during a shot and transferred to the archive within minutes after the shot.

Data Reduction

A standard set of data reduction routines is used in support of system operations to allow assessments to be made immediately after the shot. Detailed reduction of most target diagnostic data is performed by the investigators well after the shot.

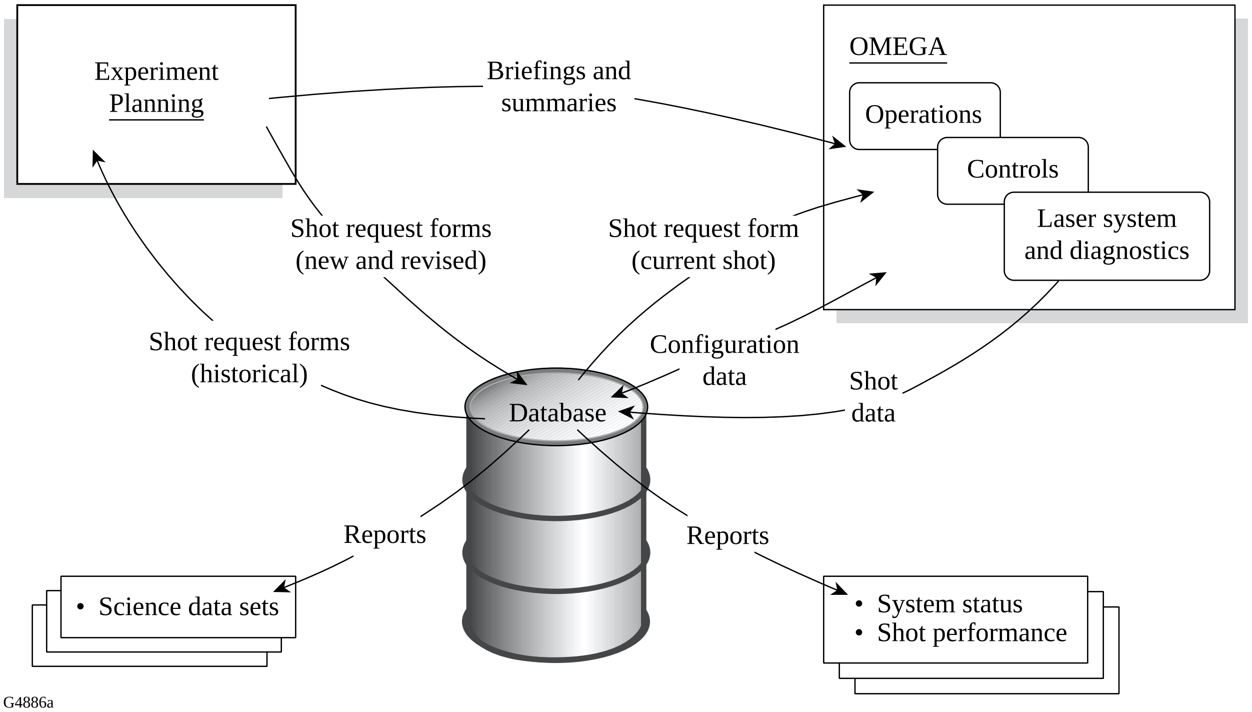


Figure 1.9-5
The OMEGA database plays a significant role in the planning, execution, and evaluation of shots. The detailed plans for experimental campaigns are embodied in Shot Request Forms (SRF's), which are stored in the database. SRF data is used to configure the OMEGA system for the shot. On-the-shot data acquired by the system and the laser and target diagnostics is recorded in the database.