OMEGA EP
System Operations Manual
Volume VII–System Description

Chapter 9: Facility and Safety Interlocks

Chapter 9
Facility and Safety Interlocks

9.0 INTRODUCTION

Personnel safety is of primary importance in the design of the OMEGA EP Laser System as it is with the current operation of the OMEGA Laser System. This chapter will discuss both the facility and systems involved with the safety monitoring and interlock features.

9.1 EXTENDED LLE FACILITY

The OMEGA EP Laser System is housed in a new building (the Robert L. Sproull Center for Ultra High Intensity Laser Research) located to the south of the existing LLE facility. The north end of the building is adjacent to the OMEGA Target Bay, and the OMEGA EP Laser System runs north–south. Figure 9.1 is a schematic drawing of the OMEGA EP Laser Facility in relation to the OMEGA Target Bay.

SWBR Architects & Engineers, P.C., a local Rochester architectural firm, designed this facility.[1] Construction of the new facility began in July 2003 and was completed by LeChase Construction in February 2005.

9.1.1 Building

9.1.1.1 Laser Slab Construction

The most significant structural feature of the OMEGA EP Laser System is a concrete box-beam 83 ft wide, 263 ft long, and one story (14 ft) high, which serves as a rigid "optical table." This optical table rests on a bed of compacted gravel and is structurally independent from the laboratory building that encloses it. This structural approach was based on the success of the original OMEGA facility design, which provides the high degree of vibration isolation[2,3] that is necessary for precision laser operations. The area inside the box-beam on the lower level contains the Diagnostic Bay, the Laser Sources Bay, and two Capacitor Bays, which house the power conditioning system that powers the laser amplifiers. Figure 9.2 is a schematic south elevation view of the OMEGA EP building showing the box-beam structure that forms a stable floor for the major optical elements in the Laser Bay located on the upper level. The rebar-reinforced concrete floors are 30-in. thick.

9.1.1.2 Laser Slab Enclosure

Surrounding this beam-box structure is a conventional building envelope, consisting of a steel-framed structure with brick-faced, reinforced concrete-block walls and a metal roof.

9.1.1.3 Ancillary Support Areas

Supporting spaces include the OMEGA EP Control Room, personnel offices, the Optics Assembly Area (OAA), shipping and receiving, and mechanical support spaces. The primary mechanical room houses boilers, chillers, pumps, a DI water plant, air handlers, electrical switchgear, and building controls.

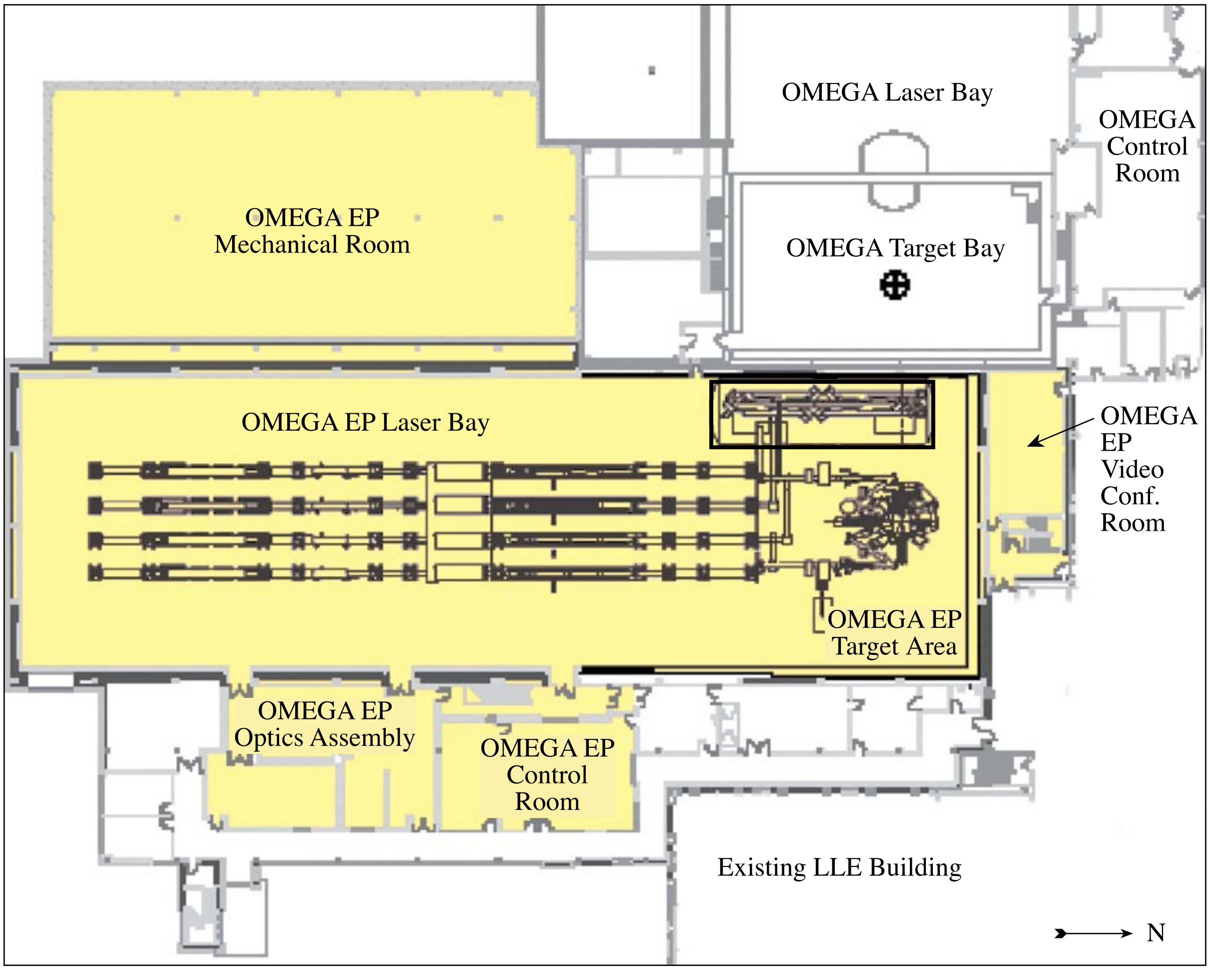

Figure 9.1
Plan view of the extended OMEGA facility. The four OMEGA EP beamlines, the grating compressor chamber, and the OMEGA EP target chamber in relation to the existing OMEGA facility are shown.

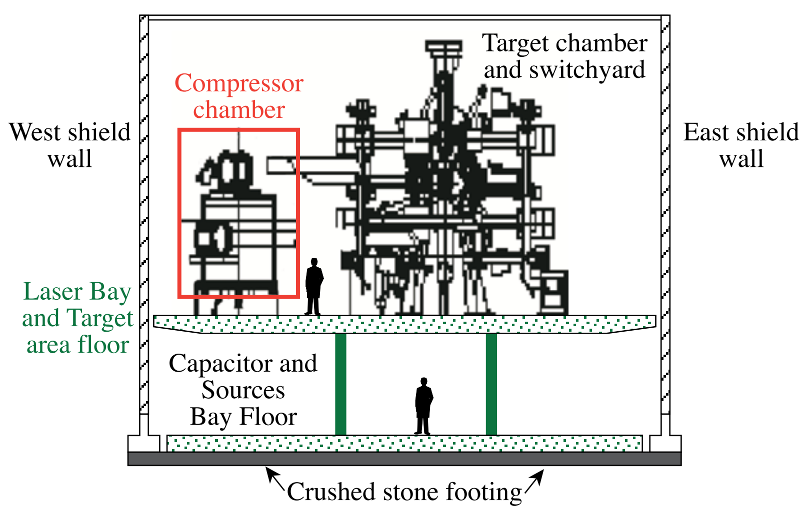

Figure 9.2
South elevation view illustrating the structural base of the OMEGA EP facility. A lower concrete slab forms the Capacitor Bay floor and is connected via two concrete walls to an upper concrete slab that supports the laser system. The remainder of the building rests on a separate foundation.

Two overlapping overhead cranes, each having 10-ton capacity, are used to hoist loads over the full length of the Laser Bay. A 14 ft × 18 ft rolling door in the southeast corner of the Laser Bay allows equipment to be hoisted into the building from the loading dock area.

The OMEGA EP Control Room is located along the east wall of the Laser Bay with convenient access to the Laser and Sources Bays, as well as the OAA. A viewing gallery for the target area and Laser Bay is located above the north end of the Laser Bay.

The facility includes a vacuum system (Sec. 9.1.3) capable of supporting the roughing vacuum ($>10^{-3}$ Torr) requirements of the OMEGA EP Laser System and the circulation of pressurized helium in support of the cryogenic pumps. The roughing system consists of commercial dry vacuum pumps and connecting stainless steel piping. These vacuum pumps are located in the OMEGA pump house and are vibrationally isolated from the Laser Bay.

9.1.2 Mechanical

The heating, ventilation, and air-conditioning (HVAC) system is designed to maintain the following conditions within the Laser Sources Bay and the Laser Bay:

- Clean room Class 1000
- Temperature: 70°F±0.5°F
- Humidity: 40% RH ±5%

Four fans operate individually at 40,000 cfm and supply approximately 15 air exchanges/hour through HEPA (high-efficiency particulate air) filters with diffusers to provide this level of cleanliness. Class 1000 clean room conditions are also maintained in several areas that connect to the Laser Bay, including the gowning room, a clean corridor, and the OAA glass and metal ultrasonic cleaning areas. The OAA coating clean room is maintained at Class 100 and has provisions for utilizing a temporary air handler bypass loop to stop airflow during critical optical coating operations.

Modular, variable-air-volume (VAV) units service the Capacitor Bays. Make-up air to the four Laser Bay air-handling units is provided through a 100%-outside-air custom unit with a humidifier section. The make-up air supply duct has a side-stream, desiccant-type dehumidifier to precondition the make-up air. Make-up air to each air-handling unit is provided through a VAV box to maintain constant make-up air rates and proper room pressurization.

9.1.3 Mechanical Vacuum System

The central mechanical vacuum system located in the pump house complements the cryogenic high-vacuum pumps that are integrated into each of the large vacuum chambers in the OMEGA EP Facility. The mechanical vacuum system uses a network of stainless steel pipelines to connect two sets of mechanical vacuum pumps to all areas of OMEGA EP requiring vacuum as low as 10^{-3} Torr. These areas include the spatial filters, the plasma-electrode Pockels cells (PEPC's), the grating compressor chamber (GCC), the beam tubes, the target chamber, the backing of turbomolecular pumps, and regeneration vacuums for cryogenic pumps. A simplified schematic of the mechanical vacuum system is shown in Fig. 9.3.

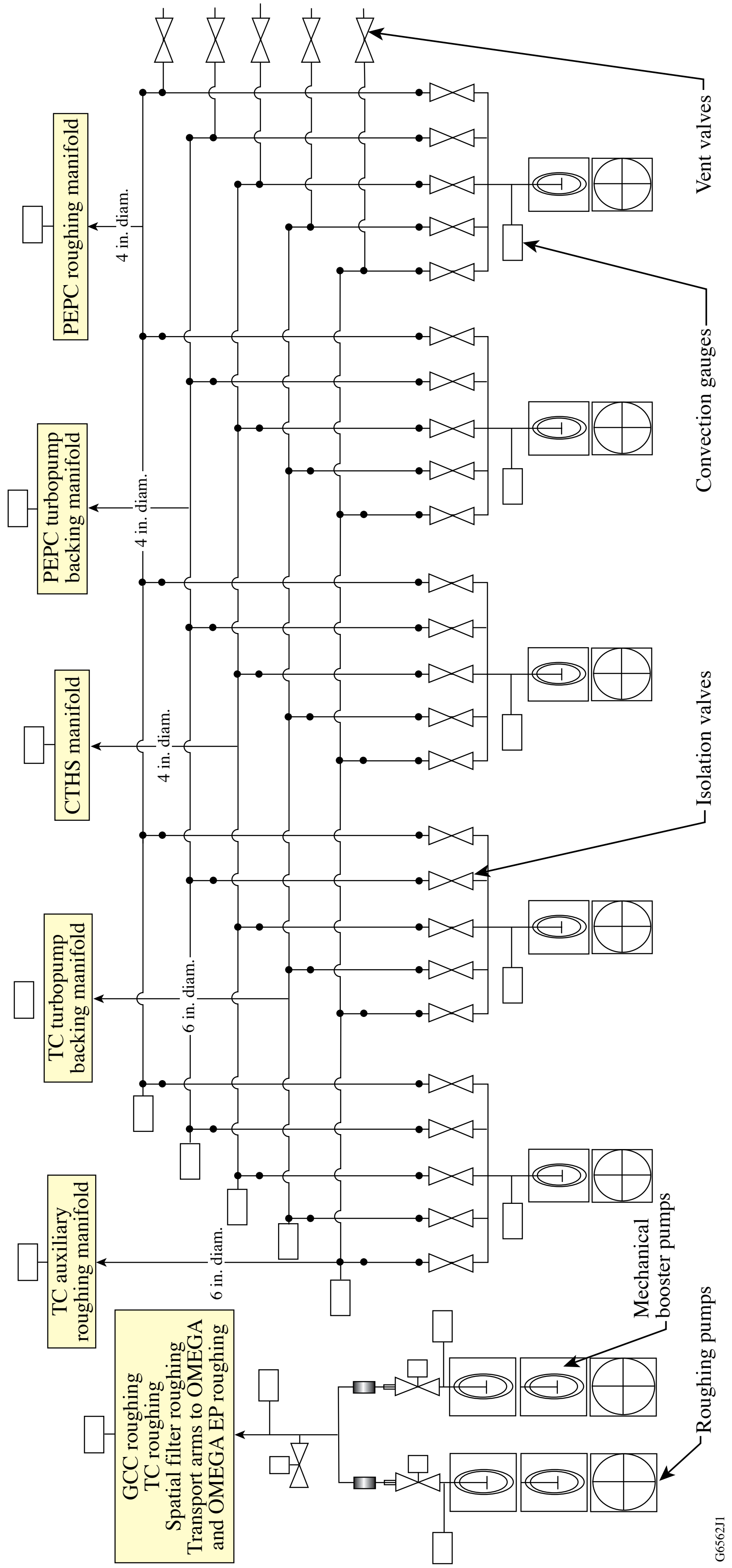

Figure 9.3
Pump house roughing system schematic for OMEGA EP.

The use of dry pumps similar to existing OMEGA roughing pumps streamlines operation, maintenance, and repairs. Rootes-type boosters backed by hook/claw dry pumps provide a clean, oil-free vacuum without the use of cryogenic traps. The installation of multiple pumps that can be switched among any of the manifolds allows operation to continue during maintenance or repair of up to two pumps. Additionally, this deployment scheme allows the use of multiple pumps on a single manifold to deliver very high performance for high-load operations such as the GCC pump-down.

Two separate vacuum-piping systems are deployed to achieve economical operation and acceptable system performance over two operating ranges. The first is a low-flow system to support PEPC's and auxiliary devices associated with the target chamber, e.g., the ten-inch manipulators (TIM's). The second is a higher-flow system deployed to pump out the target chamber itself, the GCC, the beam-transport tubes, the spatial-filter tubes, and the cryogenic pump regeneration vacuum.

Once the OMEGA EP beam transport tubes are connected to the OMEGA target chamber and joint shot operations are underway, there is a contamination risk to the OMEGA EP system due to the presence of tritium in the OMEGA target chamber. This risk will be mitigated by venting the OMEGA EP GCC and associated beam transport cavities to the OMEGA Tritium Recovery System (TRS). This emission control system will not be required for the initial OMEGA EP target chamber operations.

9.2 OMEGA EP Beam Transport to the Existing OMEGA Facility

An evacuated beam transport arm connects the OMEGA target chamber and the OMEGA EP GCC through their common north-south shield wall. Vacuum gate valves permit isolation for servicing as required. Safety procedures restricting personnel access to designated areas enable independent shots on OMEGA and OMEGA EP, minimizing the risk of exposure to radiation.

9.3 Shielding System

Like the OMEGA radiation protection system, OMEGA EP uses a combination of shielding, distance, monitoring, and shot types/numbers to limit radiation exposure in all accessible areas to <25% of the general population radiation exposure limit of 100 mRems/yr. The shielding design is based on an analysis of the shielding requirements performed by Advanced Energy Systems, Medford, New York,[4] and a shot exposure rate of 100 shots per year that produce either the maximum x-ray and/or maximum neutron yields as indicated below.

Source function:

X-ray maximum	
Spectrum	$I = I_0 e^{-h\nu}/kT$ with kT = 0.1 MeV, 1 MeV, 10 MeV
Energy/shot	E = 1000 J
Solid angle	4π @ kT = 100 keV
	90° cone @ kT = 1 MeV
	45° cone @ kT = 10 MeV
Neutron maximum	
Spectrum	E = 2.45 MeV
Number	$n < 10^{12}$
Solid angle	4π

The shielding on both the north wall and the portion of the wall directly east of the target chamber exceeds 30 in. of concrete and is described in detail in the "OMEGA LLE Radiological Controls Manual."[5] Closed access procedures will ensure personnel safety during shot operations. Moreover, in anticipation of higher energy shots in the future, the facility has been built to accommodate lead shielding on the north shield wall that can be added later if the radiation evaluation indicates a need for additional shielding.

9.4 Building Utilities and Safety Interlock

The three major classes of hazards addressed by the interlock functions built into the utilities that support the laser system are

- control of the high-voltage power sources present in the laser amplifiers,
- control of the warnings issued when laser emissions are present that could constitute an eye hazard, and
- active and passive monitoring of personnel locations in the bays.

These and basic facility-monitoring features are included in the OMEGA EP Building Utilities and Safety Interlock[6] system. This system is an assembly of hardware and software subsystems that provides the Shot Director with the means to safely manage the laser sources and facility access control. It also provides the monitoring functions for the building air, the amplifier de-ionized water-cooling system and the read-back capability for the remote radiation monitors that are mounted throughout the facility. All of the system I/O is buffered through a GE-FANUC Programmable Logic Controller (PLC), which is located in the OMEGA EP mechanical room.

9.4.1 Graphical User Interface

The OMEGA EP Building Utilities and Safety Interlock (BUSI) Graphical User Interface (GUI) illustrated in Fig. 9.4 provides a means to quickly and easily analyze the status of many safety features including

- 500-kVA control
- door accessibility
- radiation warning lights
- ambient lighting
- building air monitoring
- de-ionized water
- laser source enablers for the Laser Bay

The BUSI-GUI resides at the Shot Director's console in the OMEGA EP Control Room. The BUSI is OMEGA Intercommunication Protocol (OIP) compliant and supports the Shot Director's control of access to different areas depending on the shot type. All required interlocks and safety features must be engaged before the GUI allows a laser shot to be initiated. More details can be found in the OIP document[7] and the "Overview: LLE Shot Operations Control" described in Sec. 2.2 of C-AJ-R-002.[6]

The alignment laser sources enable box has multiple selections described as LB-IRAT, LB-UVAT, and SPDP. Enabling a laser source entails closing a contact that allows an operator to manually turn on an individual source via a key or some other method. All Laser Bay IRAT and SPDP sources are enabled or disabled by either the LB-IRAT or SPDP button; likewise for the target area UVAT source. The sources in the Laser Sources area are locally interlocked to warning lights. These laser warning lights are always on, requiring any personnel entering the Laser Sources area to wear eye protection.

All laser sources in the Laser Bay are interlocked through the PLC. When light is propagated from the Laser Sources Bay, the operator begins the procedure by first enabling it from the EP-BUSI GUI. Then, a timer starts and an announcement is made warning personnel in the bay that a new laser source will be started. Personnel will have sufficient time to put on eye protection. Laser warning lights at the bay entry points will be turned on at this time. When the designated time has passed, the PLC will remove the interlock and the source power supply will be enabled. Remotely controlled mechanical shutters are positioned between the Laser Sources Bay and the Laser Bay to ensure that laser beams cannot propagate without the knowledge and consent of the beamlines personnel.

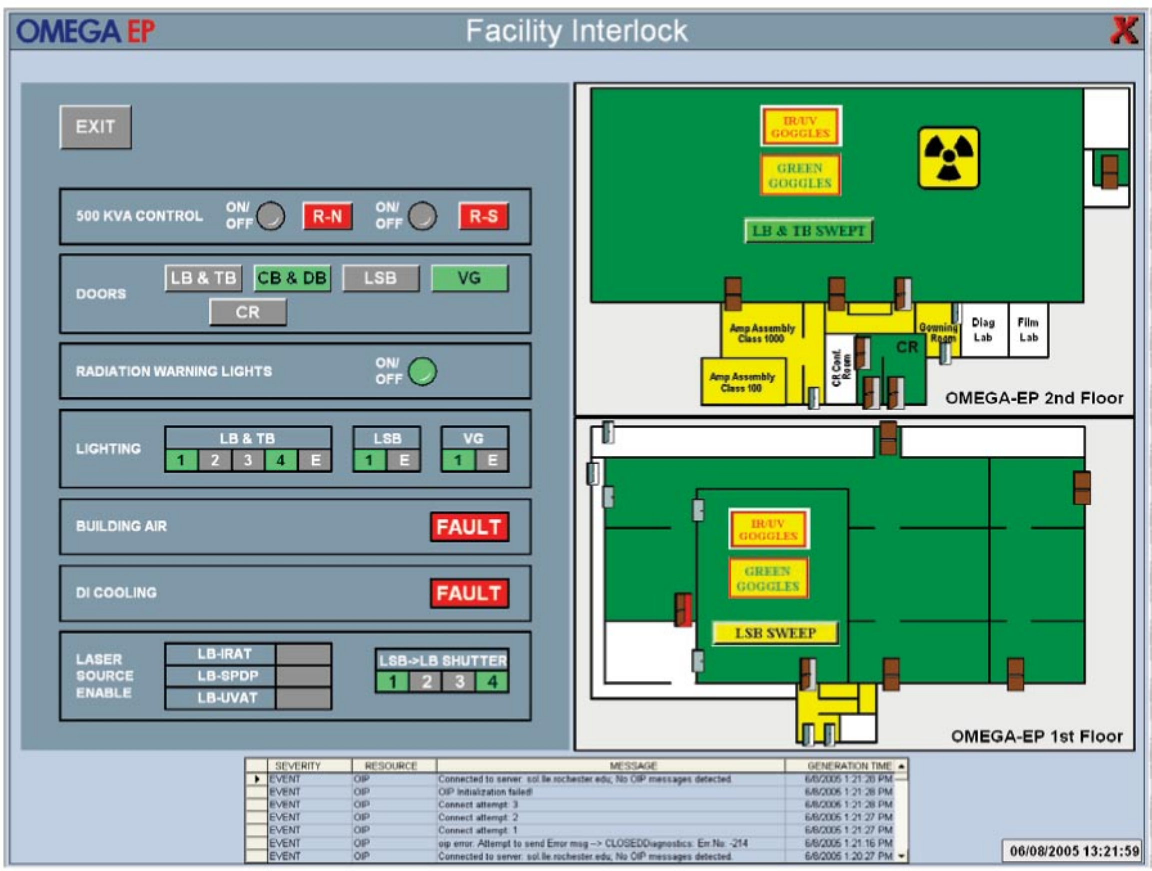

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Figure 9.4
OMEGA EP Facility interlock graphical user interface.

9.4.2 Surveillance and Communications

Twenty-eight surveillance cameras placed in remote or high traffic areas provide additional safeguards (Figs. 9.5 and 9.6). These surveillance cameras are intended to augment the physical sweep of bay areas prior to a shot sequence.

A public address (PA) system is installed in the facility to provide laser status announcements and shot sequence information to personnel working in the facility. This system can be accessed either manually from the Shot Directors' console in the Control Room or automatically from the interlock computer. The latter option has been provided so that automated announcements concerning bay-access changes, shot-state changes, and laser safety status updates can be made directly from the interlock computer. The PA system also allows for input from OMEGA. During joint shot operations, the PA system is connected to the OMEGA EP system to announce the shot sequence. It can generate tones for general calls or warnings of impending shots and also deliver prerecorded messages.

For point-to-point communication within the bay areas and out to the Control Room, a three-channel, full duplex communications system has been installed. The backbone of this system is an extensively wired network. Tethered headsets located at each control station allow communication between operators and bay personnel. In each bay a radio base station is wired into the backbone system. Each station acts as a two-way repeater for up to four wireless belt packs. Personnel in the bay who need to be highly mobile use these wireless belt packs when tethered communication is not practical.

9.5 500-kVA Substation

The 500-kVA substation, located in room 5011, provides 208 VAC to each power conditioning unit (PCU) in the Capacitor Bays. The BUSI PLC controls the two 1200-A breakers that connect the substation to the buss ducts that provide power to the north- and south-bay PCU's. The BUSI system provides for power dump buttons within the control circuit so that breakers can be tripped to discharge the capacitors manually without computer assistance. Any dump button in the circuit will trip both the north and south breakers. These dump buttons are located primarily in the Capacitor Bays with an additional button located at the Shot Director's station. In addition, two reset buttons located at either end of the connecting hallway between the north and south bays eliminate the need to return to the substation in the mechanical room when a reset is required. Next to each reset button is a key lockout box to be used by the power conditioning technicians during maintenance. There is a reset button and a lockout box for each half of the system. Figure 9.5 details the physical layout of the dump circuit components on the first floor of the facility.

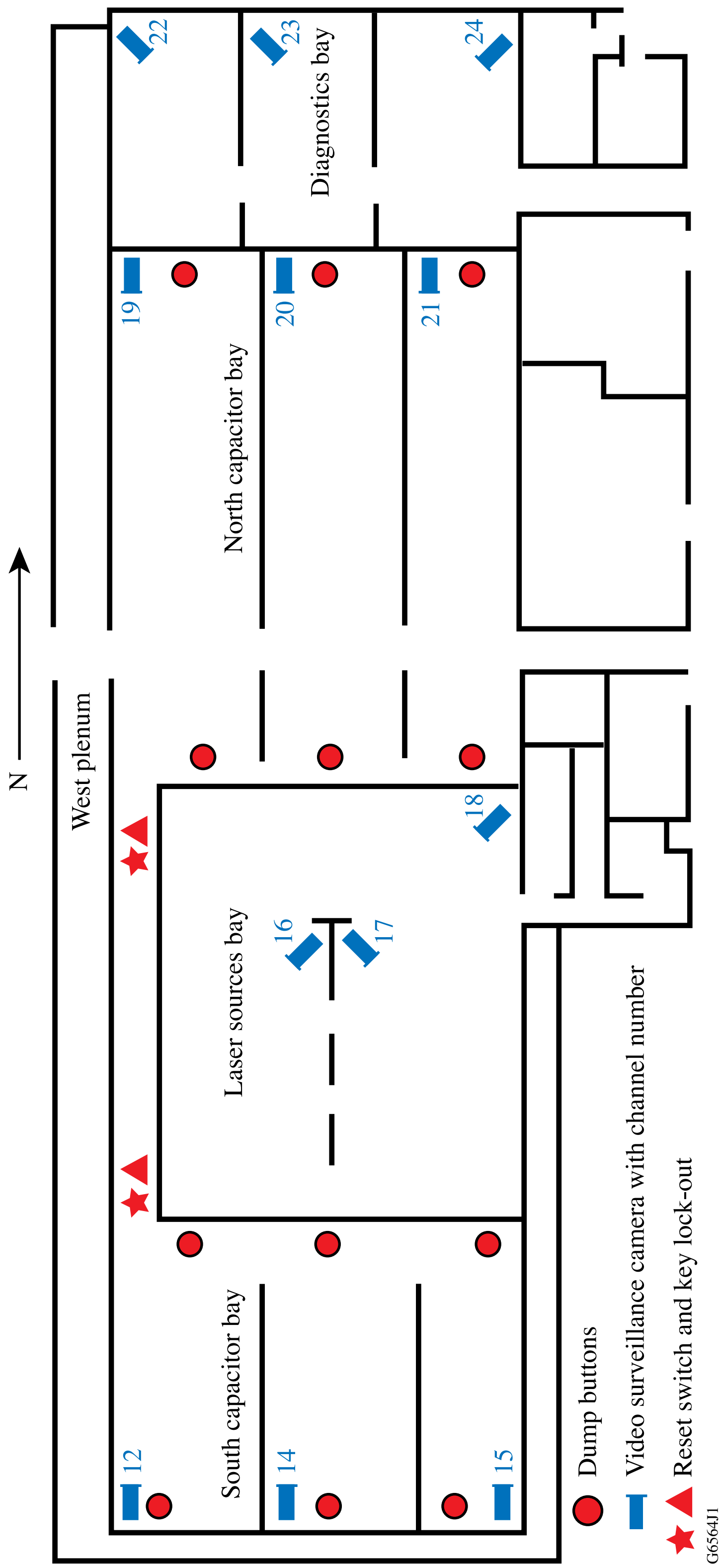

Figure 9.5
First-floor video surveillance, first-floor dump buttons, reset switches, and lockouts.

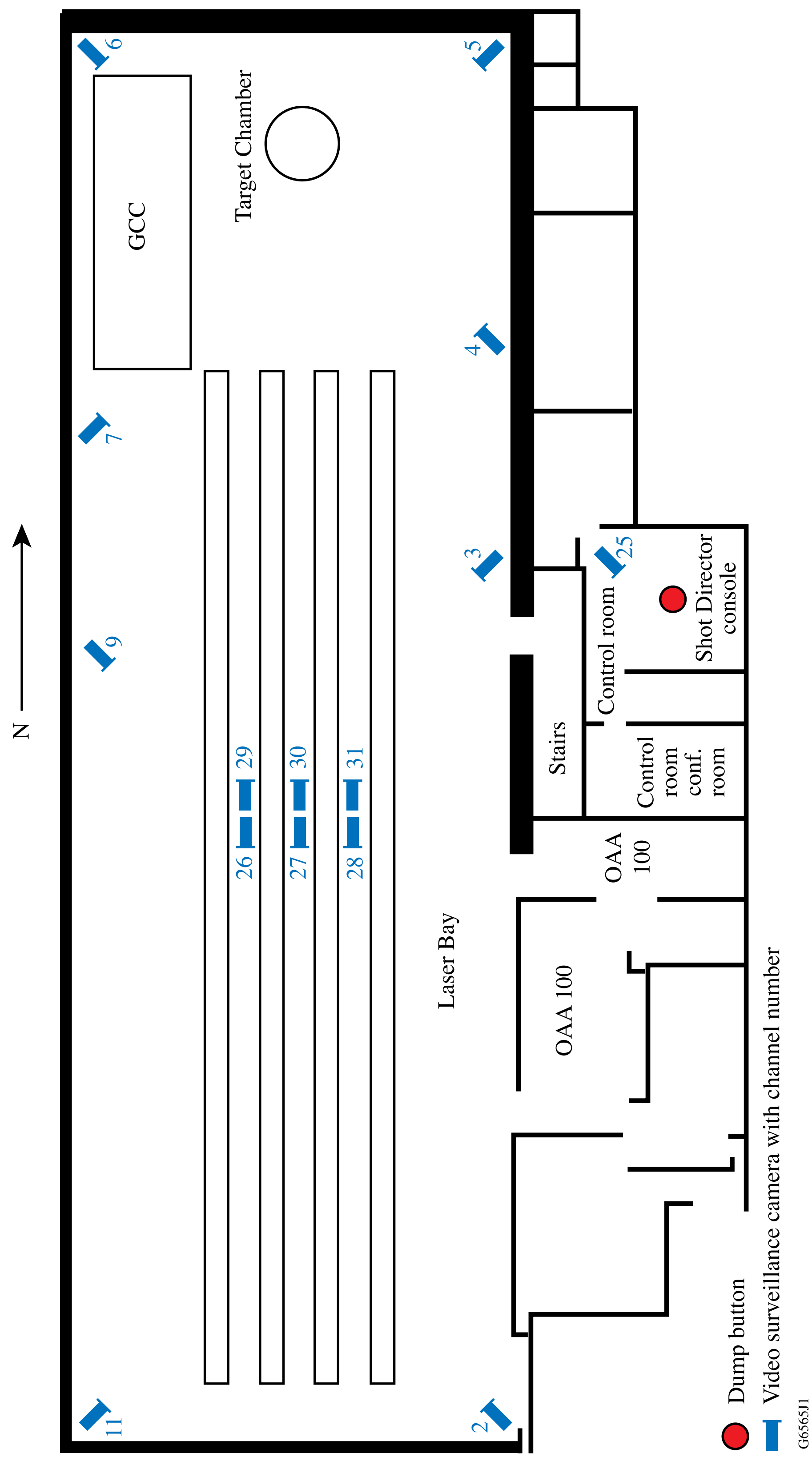

Figure 9.6
Second-floor video surveillance.

9.6 GROUNDING

Electrical grounding is important in the design of any system for two reasons: (1) personnel safety and (2) the potential for electrical noise and equipment damage due to electromagnetic interference (EMI). Good design practices were applied to achieve safe, reliable operations and to obtain high-quality shot data. These practices include the selection of appropriate cabling and cable connectors, the location of equipment, and proper grounding techniques. Grounding techniques that were used on the OMEGA system were applied to OMEGA EP.[8] The objectives of these techniques are

1. to provide fault protection for personnel safety,
2. to avoid multiple ground paths, and
3. to minimize the included area of ground loops that cannot be avoided.

These basic grounding philosophies were followed:

- All power wiring circuits were designed, built, and inspected in compliance with the applicable NEC/TOB/ANSI standards.

- The metallic structures of the laser amplifiers are isolated from their supporting structures but grounded to their respective power conditioning units.

- Electric power and control/signal cabling do not compromise the isolation/grounding provisions.

- Plumbing connections for gases, cooling, and vacuum do not compromise the isolation/grounding provisions.

The OMEGA EP system grounding tree is shown in Fig. 9.7. A buried building ground cable surrounds the LLE complex. This bare copper cable (#4/0 AWG) is ~4 ft below grade level and provides attachment points for the main building's grounding bar, I-beam support structure, water mains, RG&E primary power feed, and XIT™* fields. Lightning rods that are placed along the edge of the building roof are cabled along the I-beam structure and terminated on the buried building ground cable. Grounding rods are attached to the buried ground cable at numerous locations around the building. The XIT™ ground system provides a low-impedance ground connection to dissipate high-voltage energy or other electrical system faults.

Each structure that supports one or more laser amplifiers is independently connected to the integrated PCU ground buss for that amplifier. Each disk amplifier is isolated from its supporting structure to 30 kV. The body of each amplifier is grounded through the ground bar on the amplifier I-beam structure, while each PCU is grounded to either the NKGB or the SKGB ground, depending on its location. More details on grounding can be found in the OMEGA EP System Grounding Plan S-AC-G-018.

*The XIT™ is a trademarked buried electrode grounding system manufactured by Lyncole XIT Grounding.

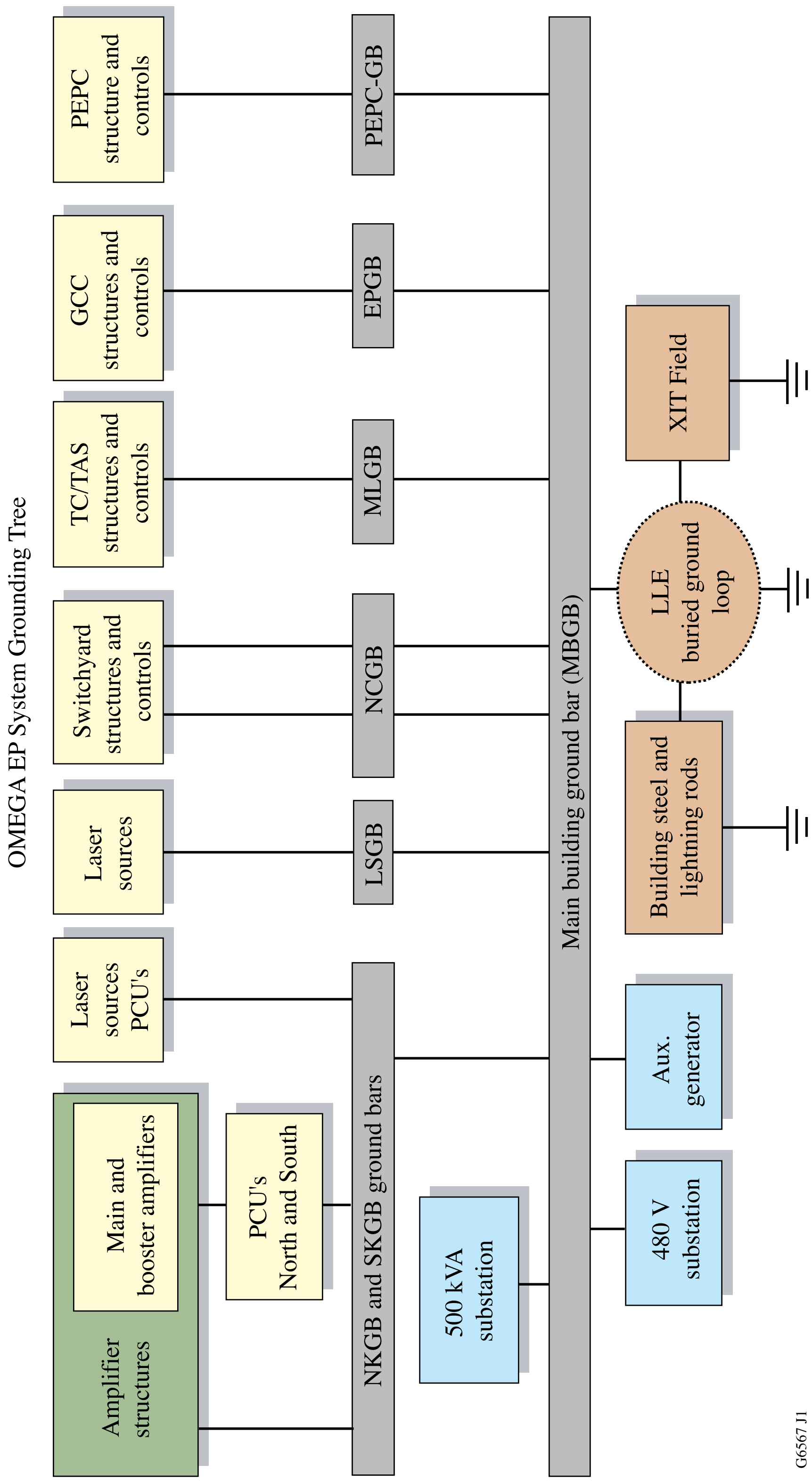

Figure 9.7
OMEGA EP Laser System's grounding tree.

9.7 REFERENCES

1. "Petawatt Laser Addition to the Laboratory for Laser Energetics, University of Rochester," Schematic Design Report, G-AB-M-001, SWBR #01185, SWBR Architects & Engineers, P.C. (30 May 2001).

2. "OMEGA Upgrade—Structural Finite Element Analysis: Summary Report," K-AB-M-012; "OMEGA Target Mirror Structure: Vibration Test Report," K-AB-M-013).

3. "Floor Vibration Analysis: OMEGA EP Addition," Sigmadyne, Inc., URLLE-0003-003, K-AB-M-009; "Floor Vibration Analysis: OMEGA EP Addition with Updated Geometry," Sigmadyne, Inc., URLLE-0003-004, K-AB-M-010; "Results of the OMEGA EP: Building Vibration Analysis," K-AB-M-011.

4. "Radiation Safety and Effects Analysis for OMEGA-EP," report prepared for the University of Rochester (LLE) by Advanced Energy Systems, Inc., Medford, NY 11763 (31 July 2002).

5. LLE Radiological Controls Manual, LLEINST 6610B, S-AA-M-16 (12 June 1995).

6. "OMEGA EP—Building Utilities and Safety Interlock Requirements (EP-BUSI) Specification," C-AJ-R-001; "OMEGA EP—Building Utilities and Safety Interlock (EP-BUSI): Software Requirements Document," C-AJ-R-002; "OMEGA EP—Building Interlock System: Conceptual Design Review," C-AJ-M-004-A; "OMEGA EP—Building Interlock System: Final Design Review," C-AJ-M-005; "OMEGA EP—Video System: Conceptual Design Review," C-AL-M-001; "OMEGA EP—Video System: Final Design Review," C-AL-M-002.

7. "Definition: OMEGA Intercommunication Protocol," S-AA-M-020.

8. "OMEGA EP—System Grounding Plan," S-AC-G-018.

Appendix A

Glossary of Acronyms

ANSI	American National Standards Institute
AWG	American Wiring Gauge
BUSI	Building Utilities and Safety Interlock
CTHS	Cryogenic Target Handling System
DI	De-ionized
EMI	Electromagnetic interference
EP	Extended Performance
EPGB	EP GCC ground bar
GB	Ground bar
GCC	Grating Compressor Chamber
GUI	Graphical user interface
HEPA	High-efficiency particulate air
HVAC	Heating, ventilation, and air conditioning
I/O	Input/output
IRAT	Infrared alignment table
LB	Laser Bay
LLE	Laboratory for Laser Energetics
LS	Laser sources
LSGB	Laser sources ground bar
MBGB	Main building ground bar
MLGB	Main laser TC/TAS ground bar
NCGB	North capacitor ground bar
NEC	A corporation (formerly Nippon Electric Company, Ltd.)
NFPA	National Fire Protection Association
NKGB	North kVA ground bar
OAA	Optics Assembly Area
OIP	OMEGA Intercommunication Protocol
PA	Public address
PCU	Power conditioning unit
PEPC	Plasma-electrode Pockels cell
PEPC-GB	PEPC ground bar
PLC	Programmable logic controller
RG&E	Rochester Gas & Electric
SKGB	South kVA ground bar
SPDP	Short pulse diagnostic package
TAS	Target Area Structure
TC	Target Chamber
TIM	Ten-inch manipulator
TOB	Town of Brighton
TRS	Tritium Recovery System
UVAT	Ultraviolet alignment table
VAV	Variable air volume
XIT™	The XIT™ (buried electrode grounding) system