SLAC-PUB-13497
January 2009

LASER SAFETY FOR THE EXPERIMENTAL HALLS AT SLAC'S LINAC COHERENT LIGHT SOURCE (LCLS)*

Michael Woods[1], Perry Anthony[1], Ken Barat[2], Sasha Gilevich[1], Greg Hays[1], William E. White[1]

[1] SLAC National Accelerator Laboratory,
2575 Sand Hill Rd., Menlo Park, CA 94025

[2] Lawrence Berkeley National Laboratory,
1 Cyclotron Rd, Berkeley, CA 94720

Abstract

The LCLS at the SLAC National Accelerator Laboratory will be the world's first source of an intense hard x-ray laser beam, generating x-rays with wavelengths of 1nm and pulse durations less than 100fs. The ultrafast x-ray pulses will be used in pump-probe experiments to take stop-motion pictures of atoms and molecules in motion, with pulses powerful enough to take diffraction images of single molecules, enabling scientists to elucidate fundamental processes of chemistry and biology. Ultrafast conventional lasers will be used as the pump. In 2009, LCLS will deliver beam to the Atomic Molecular and Optical (AMO) Experiment, located in one of 3 x-ray Hutches in the Near Experimental Hall (NEH). The NEH includes a centralized Laser Hall, containing up to three Class 4 laser systems, three x-ray Hutches for experiments and vacuum transport tubes for delivering laser beams to the Hutches. The main components of the NEH laser systems are a Ti:sapphire oscillator, a regen amplifier, green pump lasers for the oscillator and regen, a pulse compressor and a harmonics conversion unit. Laser safety considerations and controls for the ultrafast laser beams, multiple laser controlled areas, and user facility issues are discussed.

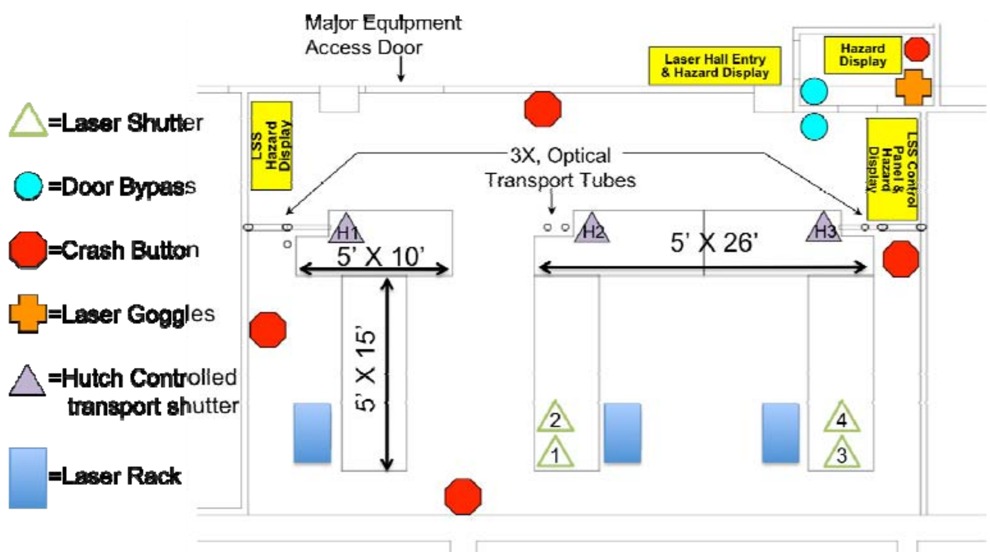

Figure 1: Floor plan of the NEH Laser Hall

* Contributed to the 2009 International Laser Safety Conference, Reno, NV; www.laserinstitute.org/conferences/ilsc.
Work supported by the U.S. Department of Energy under contract number DE-AC02-76SF00515.

1. Introduction and Facility Description

The LCLS machine [1] uses the last third of the 2-mile electron linear accelerator (LINAC) at SLAC and includes a new injector, which uses a Class 4 laser system to generate a high brightness, low emittance electron beam from a photocathode [2].The LCLS Near Experiment Hall (NEH) contains a centralized Laser Hall, which houses up to three Class 4 laser systems as shown in Figure 1. The laser beams can be transported from the Laser Hall through vacuum tubes to any of three experimental Hutches located in the sub-basement of the NEH. There are 4 independent Laser Controlled Areas (LCAs) in the NEH for the Laser Hall and each Hutch. Each LCA has an independent engineered Laser Safety System (LSS). The “treaty point” between the Laser Hall and Hutch LCAs is the respective transport shutter (H1, H2 or H3). The transport shutter and optical transport tube to the Hutch are part of the Hutch LCA.

Hutch 1 hosts the Atomic, Molecular and Optical (AMO) Experiment for LCLS [3]. Hutch 1 is located on the basement level of the NEH, directly beneath the Laser Hall (see Figure 2). The main laser beam is transported from the Laser Hall through an evacuated beam tube to the Hutch 1 optical table.

The x-ray beamline is also shown in Figure 2. There is an engineered Personnel Protection System (PPS) to prevent personnel from accessing the Hutch when there is a radiation hazard from the x-ray beam. The PPS operates independently of the Laser Safety System (LSS), but provides input to the LSS for whether the Hutch PPS state is OPEN ACCESS or NO ACCESS. During NO ACCESS, the X-ray Door is closed, locked and interlocked and the laser door is open; in this mode, the Hutch becomes a Class 1 enclosure with an embedded Class 4 laser.

When the PPS is in OPEN ACCESS, there are two x-ray stoppers upstream of the Hutch that are inserted to protect personnel. The Hutch laser system can then be operated either as a Class 1 laser or as a Class 4 laser. The laser in the Hutch can be completely contained within a sealed, light-tight enclosure, allowing Class 1 operation. In Class 1 mode, the table enclosures must be in place and the Exit Shutter closed. When the Exit Shutter is opened, the laser beam can be transported to the AMO experimental apparatus. When the enclosures are removed or the Exit Shutter is Open, Hutch 1 becomes a Class 4 LCA if the laser beam is enabled. In Class 4 mode, the Laser door is closed, locked and interlocked and the x-ray door is open.

The LCLS Near Experimental Hall with 3 experimental Hutches is a user facility to support researchers from SLAC, the university community and other institutions. The facility is planned to operate for up to 10 months per year with beams available for experiments 24 hours per day, 7 days per week. Only some of the experimenters that will access the Hutches will become qualified laser personnel and they may need relatively frequent access to their experimental equipment. These features of the facility, together with multiple laser controlled areas connected by laser beam transport tubes, provide special challenges for the laser safety system and policies. Laser safety for the NEH is described in the subsequent sections on Hazards Description, Personnel and Training, Engineering Controls, Administrative Controls and Procedures, and Protective Eyewear [4].

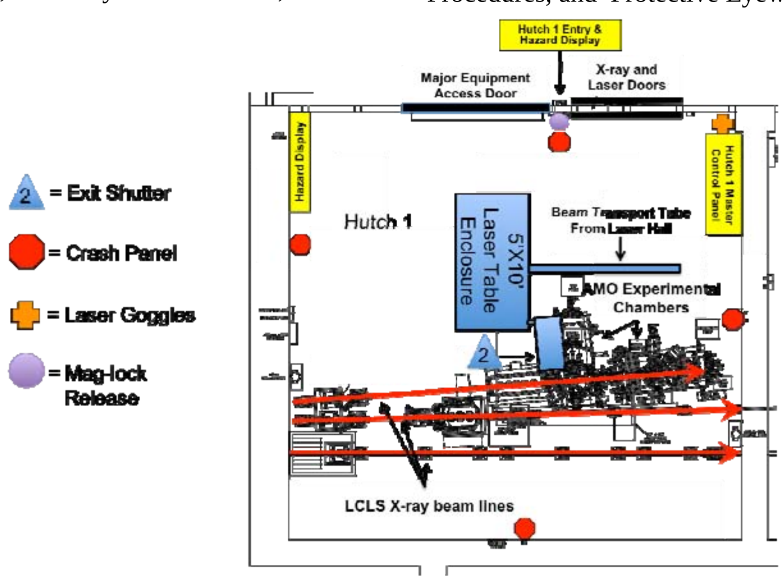

Figure 2: Floor Plan of Hutch 1

2. Hazards Description

2.1 Laser Hall

2.1.1 Laser hazards. The Laser Hall will initially have two identical laser systems. The main components of each system are: i) a Ti:sapphire oscillator: FemtoLaser Synergy 20, ii) the oscillator pump laser: Spectra-Physics Millennia V, iii) a regen amplifier: Coherent Legend USP-HE, and iv) the regen pump laser: Coherent Evolution 30.

The system employs the chirp pulse amplification (CPA) approach and contains pulse stretcher and pulse compressor that change the pulse duration according to the system components requirements and the output radiation specifications. The repetition rate is changed by Pockels cells and polarizers, which gate single pulses. A Dazzler (acousto-optic programmable dispersive filter) is used for pulse shaping. A Class 3R He-Ne alignment laser is also used. Laser hazard parameters are summarized in Table 1.

2.1.2 Electrical hazards. The laser system is diode pumped (it does not contain flash lamps), and therefore there are no high voltage laser power supplies. A low current 5 kV hazard can be found inside the Pockels' cell high voltage power supply and housing.

2.1.3 Toxic materials. Small quantities of methanol and acetone for optics cleaning are present.

2.1.4 Other hazards. Several other hazards are present in the Laser Hall. Vacuum optical transport tubes are used to propagate the laser beam to the Hutches. A nitrogen purge line is available to connect to the vacuum tubes when they are serviced.

Table 1: Laser Hall laser hazard parameters

	Wave-length, nm	Avg. Power	Pulse Width (FWHM)	Energy/ Pulse,	Repetition Rate	$1/e^2$ Beam Diameter (mm)	MPE (small source) W/cm^2	OD Req'd for full protection	ANSI Class
After oscillator.	800	520 mW	20 fs	7.5 nJ	69 MHz	2 mm	1.6e-3	2.9	4
After regen amplifier	800	5 W	200 ps	5 mJ	1 kHz	1.5 mm	7.9e-5	5.2	4
Oscillator Pump Laser	532	5.0 W	CW	--	CW	2.5 mm	2.6e-3	3.7	4
Pump Laser (Evolution)	527	20 W	250 ns	20 mJ	1 kHz	3 mm	1.3e-4	5.6	4
He-Ne Laser	633	2mW	CW	--	CW	2 mm	2.6e-3	-	3R

2.2 Hutch 1

2.2.1 Laser hazards. The main components of the Hutch 1 laser system are: i) the uncompressed laser transported from the Laser Hall, ii) a pulse compressor, and iii) a harmonics conversion unit.

Uncompressed laser pulses are transported from the Laser Hall to Hutch 1 through a light tight, evacuated beam tube. The pulse duration is compressed in the pulse compressor according to the system component requirements and the output radiation specifications. The repetition rate is changed by the Pockels cells and polarizers located in the Laser Hall. In addition, a Class 3R He-Ne alignment laser is used. Laser hazard parameters are summarized in Table 2.

2.2.2 Electrical hazards. No high voltage hazards due to the laser system exist in the Hutches.

2.2.3 Toxic materials. Small quantities of methanol and acetone used for optics cleaning are present.

2.2.4 Other hazards. There are other hazards in the Hutch associated with the x-ray beamline and associated instruments. Radiation hazards are controlled by shielding, engineered safety control systems and administrative procedures. Other hazards include electrical, vacuum and pressure, and cryogenics. A complete description of these is beyond the scope of the laser safety discussion in this paper. SLAC's safety analysis and controls for these hazards are administered independently of the laser safety program.

Table 2: Hutch 1 laser hazard parameters

	Wave-length, nm	Avg. Power	Pulse Width (FWHM)	Energy/ Pulse	Repetition Rate	$1/e^2$ Beam Diameter mm	MPE (small source) W/cm^2	OD Req'd for full protection	ANSI Class
Before Compressor	800	5 W	200ps	5 mJ	1 kHz	1.5 mm	7.9e-5	5.2	4
After compressor	800	3.5 W	35 fs	3.5 mJ	1 kHz	7 mm	8.3e-6	6.0	4
After SHG	400	0.18 W	50 fs	1.5 mJ	120 Hz	10 mm	9.0e-7	5.7	4
After THG	266	0.03 W	50 fs	0.25 mJ	120 Hz	10 mm	1.0e-7	6.5	4
He-Ne Alignment Laser	633	2 mW	CW		CW		2.6e-3	0	3R

3. Personnel and Training

3.1 Laser Safety Officer (LSO). SLAC's LSO may enter the Laser Hall or a Hutch to perform safety inspections and to observe work under Laser On conditions, as well as Laser Off conditions. The LSO must be accompanied by a Qualified Laser Operator at all times and have approval from the System Laser Safety Officer during Laser On conditions.

3.2 System Laser Safety Officer (SLSO). An SLSO is assigned for each LCA by the program manager for that LCA and must be approved by the LSO. The SLSO is responsible for the LCA's Standard Operating Procedures (SOPs), for safe operations of the LCA on a daily basis, for site-specific and on-the-job training (OJT) given to Qualified Laser Operators, and for maintaining safety documentation for the LCA. The SLSO is also responsible for issuing RFIDs (radio frequency identification cards) to laser operators, which give them access to LCAs and laser operations for which they are approved. RFIDs are encoded with training and authorization information for each laser operator.

3.3 Qualified Laser Operators (QLOs). A QLO receives general and site-specific laser safety training, and is authorized to perform task-specific work on various laser system components. QLOs are issued an RFID, which is required for entry to the LCA and for controlling laser operations with the LCA's Master Control Panel.

3.4 Service Subcontractors. A laser service subcontractor may need to be in the Laser Hall or a Hutch to perform maintenance or service. These personnel must always be escorted by a QLO and abide by the same safety procedures as QLOs. Their employer provides their laser safety training and SLAC is only responsible for providing site-specific safety training. The requestor and service subcontractor jointly prepare a written procedure and safety plan for the work to be done, which must be reviewed and approved. SLAC's Purchasing department coordinates the documentation governing the service visit and notifies the LSO of the service requisition. A pre-job briefing is held with the requisitioner, the service subcontractor and the LSO (or their designee) to review the work to be done and compliance with SLAC's safety policies. The SLSO maintains a record of the visit with the LCA's safety documentation.

3.5 Visitors. Visitors are those individuals who have not met the requirements for the other personnel classifications. Normally visitors are not permitted during Class 4 operations, and would only be permitted in the Laser Hall or a Hutch when the Class 4 laser systems are disabled by removing a Master Key for the respective LCA. When the laser is running in Class 4 mode, visitors are allowed in the Laser Hall or a Hutch only under the following conditions:

- The visitor must be escorted at all times by a QLO who ensures the visitor is wearing the proper protective eyewear.
- Prior to entry by the visitor, the QLO must check the LCA to make sure the laser system is in and will stay in a state of minimal hazard during the visit. No laser alignment work is allowed during such visits.

- Visitors may only observe, and are not allowed to operate or manipulate the laser beams.

- All visitors must be 18 years or older; the maximum number of visitors is 6 persons.

4. Engineering Controls

4.1 Laser Safety System (LSS). Each of the Laser Hall and three experimental Hutches has an independent engineered LSS. Key components of each LSS are:

- LSS Enable Controller and Master Control Panel (MCP), utilizing a programmable logic controller (PLC).
- Entryway controls and interlocks
- Laser enclosure interlocks
- Laser safety shutters
- Key control and RFIDs
- Permissives to commercial laser remote interlocks
- Emergency Off buttons
- Laser hazard displays
- Activation warning system and audible alarms

The Master Control Panel (MCP) and an associated LSS Enable Controller are used to enable Class 4 operation, set operation modes, control laser safety shutters, and display laser hazard information on its control screen and local display signs. The PLC used by the MCP is a commercial DirectLogic 205 with DL260 CPU and an EPICS interface. In the Laser Hall, both the LSS Enable Controller and the MCP are located inside the Laser Hall. For Hutch 1, the MCP is located inside the Hutch while the Enable Controller is located outside the Hutch. An LSS Enable Key is required to be captured in the LSS Enable Controller to enable operations with the MCP. A QLO must also badge-in to the MCP with their RFID to access control of the MCP. The RFIDs use a commercial Radio Key RK-65KS system. The MCP will timeout and require another badge-in for further control of the LSS after 30 seconds of inactivity.

The MCP monitors interlock inputs from doors, enclosures and Emergency Off buttons. When the interlock requirements are satisfied for the operation mode selected, the MCP enables operation of the laser safety shutters and commercial lasers. The MCP has a touch panel with select buttons that allow control of the enabled shutters. All interlocks are latching and must be reset manually at the MCP after a failure. The MCP also checks for faults in the status of laser safety shutters; i.e. if a shutter state is found to be inconsistent with the requested state. If a fault is detected, the MCP will put the laser system into a safe state (by inserting an upstream laser safety shutter or disabling a laser remote interlock) and/or alert the personnel present. QLOs receive training to inform the SLSO and LSO of the occurrence of any laser safety shutter faults. Tables 3 and 4 give a summary of actions taken by the LSS for different interlock conditions.

The MCP display panel shows the operating mode selected, and the status of the interlocks and laser safety shutters. The MCP also displays laser hazard information on its display panel and on the hazard warning displays (locations are shown in Figures 1 and 2) indicating the status of the laser system. The wavelength defines the protective eyewear required. Remote monitoring of the status of the laser safety system is done with EPICS. EPICS is also used for password-protected remote operation of the Hutch 1 LSS components in the PPS NO ACCESS state, which is described below.

4.1.1 <u>Laser Hall Operation Modes</u>. There are three modes:

i. Normal Operation: 800nm infrared (IR) Class 4 laser beams are enabled, and can be transported to any or all of the Hutches through the optical transport tubes, depending on the LSS for each Hutch. The green (527 and 532nm) lasers have enclosures permitting Class 1 operation for them. These enclosures are interlocked to their respective laser systems and must be closed.

ii. Green Operation: IR and green Class 4 laser beams are enabled, and can be transported to any or all of the Hutches through the optical transport tubes, depending on the LSS for each Hutch.

iii. Laser Off: this is the operation mode when the LSS Enable Key is removed. Permissives to commercial laser remote interlocks are disabled, and the two laser safety shutters are closed and disabled.

4.1.2 <u>Hutch 1 Operation Modes</u>. The operation mode is partially dictated by the x-ray PPS state. In all cases when the PPS state is NO ACCESS, the Hutch becomes a Class 1 laser enclosure with an embedded Class 4 laser. In the NO ACCESS state, the H1 Transport Shutter is enabled and automatically opens; control of the two laser safety shutters in this mode is done remotely with password-protected EPICS commands. When the PPS state is OPEN ACCESS, the MCP can select one of three Operation Modes:

i. Class 1 Operation: The laser is treated as a Class 1 embedded laser system. The laser table enclosures must be closed with their interlocks satisfied. The Exit Shutter is closed and disabled. The X-ray and Laser Doors are open. If these conditions are satisfied, the H1 Transport Shutter is enabled and may be opened.

ii. Class 4 Operation: IR (800 nm), blue (400 nm), and UV (266 nm) Class 4 radiation may be present in the Hutch. The Laser Door must be closed and locked, with its interlocks satisfied. The X-ray Door is open. The laser table enclosures may be removed. Both the Transport Shutter and the Exit Shutter are enabled and may be opened.

iii. Laser Off: The Transport and Exit Shutters are both closed and disabled.

<u>4.1.3 Laser Safety Shutters</u>. Laser safety shutters block laser light from reaching unprotected personnel. These are SLAC-built shutters, using a commercial Electro-Optical Laser Safety Shutter SH-10-M-L, that are designed to fail in the closed position and have both IN and OUT photo-interrupter sensors for position read-back. The shutter is a 2 mm thick macor blade with an opaque backing to prevent diffuse transmission. Macor is a white ceramic with excellent mechanical and thermal properties for use as a high power laser shutter. An inconsistent state of the IN and OUT sensors is shown as a fault on the MCP. The shutters are closed when they are disabled. Both audible and visual activation alarms will sound for 15 seconds before the shutters are opened. Laser safety shutter locations are shown in Figures 1 and 2.

SLAC's laser safety policy requires that laser safety shutters be redundant when they have the potential to be used as an energy isolation device that stops a Class 4 laser beam from going into an uncontrolled area where there may be non-QLOs present. Redundancy is not required for the Oscillator and Amplifier Shutters in the Laser Hall, but is required for the Transport and Exit Shutters that are part of the Hutch 1 LSS. In practice, all four of these laser safety shutters are implemented as dual shutter systems. A dual shutter has 2 redundant macor shutter blades in series with independent IN and OUT sensors; it uses common control signals for these 2 macor blades.

The Laser Hall has two laser safety shutters. The Oscillator Shutter blocks the output of the oscillator, and the Amplifier Shutter blocks the output of the regen amplifier.

Hutch 1 also has two laser safety shutters. The Transport Shutter is located in the Laser Hall and permits an incoming laser beam to the Hutch when open. The Exit Shutter is located between the Hutch laser tables and the AMO experiment, and permits a laser beam to be incident on an AMO sample when open.

<u>4.1.4 Entryway Controls</u>. The Laser Hall has a double-door entry with a small entry room between the outer and inner doors (see Figure 1). Protective eyewear is stored in the entry room and is put on prior to entering the Laser Hall. The outer door is locked (from the outside only) but not interlocked, while the inner door is interlocked but not locked. The outer door is secured at all times by an electric strike plate (a Von Duprin 5100 Electric Strike). Access is granted to QLOs by verifying their identification with an RFID reader. The inner door is interlocked and a 15-second timed bypass must be activated to allow entry and egress without tripping the interlocks. An audible alarm sounds during this 15-second bypass to alert personnel of someone entering or exiting the Laser Hall.

The Hutch has two entry doors as shown in Figure 2: an outer sliding X-ray PPS door and an inner sliding laser door. The X-ray door is always closed during the NO ACCESS state and is open when the PPS state is OPEN ACCESS. It is not incorporated or interlocked to the LSS. The laser door is closed only during Class 4 operation mode in OPEN ACCESS. It is a normal hinged door, locked from the outside only, and mounted in a sliding frame. A commercial ChaseDoors Saino Fire Door will be used for this. A mechanical lock, only accessed from inside of the Hutch, secures the sliding panel. Personnel access during Class 4 operation is through the hinged door, which is secured by an electronic strike plate (a commercial HES 1006 Electric Strike). Access is granted to QLOs by verifying their identification with an RFID reader. Both the sliding panel and the hinged door are interlocked. There is no entry bypass, so each entry or exit will cause the LSS to insert both the Transport and Exit Shutters and put the laser system into the Laser Off state. Protective eyewear is stored inside the Hutch.

The Laser Hall and Hutches each have Major Equipment Access doors to allow large equipment installations. These doors are interlocked. They are also secured so they can only be opened from inside the Laser Hall or Hutch. In the Laser Hall, opening this door will insert the Oscillator and Amplifier Shutters and remove the permissive to the laser remote interlocks. In the Hutch, opening this door will insert the Transport and Exit Shutters.

4.1.5 Emergency Off buttons. Locations for these Crash buttons are shown in Figures 1 and 2. Pushing a Crash button in the Laser Hall will close the Oscillator and Amplifier Shutters and de-energize the laser racks and laser power supplies. Pushing a Crash button in the Hutch will insert the Transport and Exit Shutters.

4.1.6 Status display signs. Display signs controlled by the LSS indicate the operating mode in the Laser Hall and Hutch. Their locations are shown in Figures 1 and 2. The signs are commercial BetaBrite Electronic Message Displays.

In the Laser Hall, LASER OFF is displayed in green when the LSS Enable Key is removed. LASER IMMINENT is displayed in yellow during Normal operation mode when both LSS shutters are closed. LASER ON is displayed in flashing red during NORMAL operation mode when one of the LSS shutters is open. LASER IMMINENT GREEN GLASSES REQUIRED is displayed in yellow during Green operation mode when both LSS shutters are closed. Lastly, LASER ON GREEN GLASSES REQUIRED is displayed in flashing red during Green operation mode when one of the LSS shutters is open.

In the Hutch during the NO ACCESS PPS state, the signs display LASER ON CLASS 1 in green. In OPEN ACCESS, there are three possible displays: when the LSS Enable Key is removed or the operation mode is Laser Off, LASER OFF is displayed in green; when the LSS Enable Key is activated and the operation mode is Class 1, LASER ON CLASS 1 is displayed in green; and when the LSS Enable Key is activated and the operation mode is Class 4, LASER ON CLASS 4 is displayed in flashing red.

4.2 Beam barriers, enclosures and termination.

Both the Laser Hall and Hutch are light tight. In the Laser Hall, there are barriers around all optical tables; they are not light tight but they aid reducing stray light from leaving the table areas. In the Hutch, the optical tables all have interlocked enclosure covers to permit Class 1 operation. All beams, including any stray beams and reflections, are terminated either by beam dumps or by diagnostics equipment.

In the Laser Hall, the configuration of the pump lasers and their beam paths are seldom changed and do not require frequent access. Both the oscillator and amplifier enclosures completely contain their respective pump lasers and the green light when they are in place. The enclosures are interlocked to their respective laser systems and must be closed during Normal Operation. When the enclosures are removed, green laser hazards may be present. In this case, a QLO must change the Laser Hall MCP to GREEN MODE and special protective eyewear (Green Glasses) is worn.

Table 3: Laser Hall LSS Interlock Logic

Interlock Condition	Operation Mode	Action	Recovery
Inner door open without bypass	Normal Operation	Close shutters	Close doors, reset MCP interlock fault; then open shutters
Inner door open without bypass	Green Mode Operation	Close shutters, open pump laser interlocks	Close doors, reset MCP interlock fault; restart: turn on Pump laser, in about 10 minutes open shutters
Inner door open during bypass period	Any mode	No action	None
Outer entry door open	Any mode	No action	None
Laser Hall Emergency Stop activated	Any mode	Close shutters, de-energize laser racks	Remove LSS Enable key and re-insert; restart
LSS Enable Key removed	Any mode	Close shutters, open pump laser interlocks	Insert key; restart
Major Equipment Door Open	Any mode	Close shutters, open pump laser interlocks	Close door, Remove LSS Enable Key and re-insert; restart
Shutter readback shows inconsistent state	Any mode	Close shutters, open pump laser interlocks	Correct shutter fault; reset MCP interlock fault. Inform SLSO and LSO prior to restart

Table 4: Hutch LSS interlock logic for OPEN ACCESS PPS state

Interlock Condition	Operation Mode	Action	Recovery
Laser Door Open	Class 1 Operation	No action	None
Laser Door Open	Class 4 Operation	Close shutters and set Laser Off mode	Close Door, set Class 4 Operation Mode; then open Shutters
Major Equipment Door Open	Any	Close shutters and set Laser Off mode	Close Door, set Class 4 Operation Mode; then open Shutters
Entry Badge-In from Outside Hutch	Class 4 Operation	Close shutters and set Laser Off mode	Close Door, set Class 4 Operation Mode; then open Shutters
Hutch 1 Emergency Stop activated	Any mode	Close shutters and set Laser Off mode	Set Class 4 Operation Mode; then open Shutters
LSS Enable key removed	Any mode	Close shutters and set Laser Off mode	Insert key, enter Hutch, close Door, set Class 4 Operation Mode; then open Shutters
Laser Enclosures Open	Class 1 Operation	Close shutters and set Laser Off mode	Set enclosures as required, set Operation Mode; then open Shutters
Laser Enclosures Open	Class 4 Operation	No action	None
Inconsistent Shutter Read-back state	Any Mode	Close shutters and set Laser Off mode	Correct shutter fault. Inform SLSO and LSO prior to restart

5. Administrative Controls and Procedures

The SLSO for each of the Laser Hall and Hutch 1 LCAs is required to produce a Standard Operating Procedures document, which is approved by the LSO and the LCA facility program manager. A separate authorization form is used to approve operation of the facility for a period of 1-year, which requires successful completion of three items: an approved SOP, a test and certification of the LSS, and an LCA facility audit by the LSO. The SOP document describes the laser facility, the laser and non-beam hazards, the LSS and other engineering controls, administrative controls and procedures, protection eyewear, and personnel training. LSS certification tests and LSO audits are performed annually. The LSS certification includes testing the interlock logic summarized in Tables 3 and 4.

5.1 Laser Hall Normal Operations. The Laser Hall is engineered to be a production facility, providing up to 10 months of 24/7 continuous laser operations to enable experiments by different users in the three experimental Hutches. The laser beamline configurations will be relatively stable. Normal operations also include setting up new beamlines and alignment. Appropriate protective eyewear is required whenever the LSS Enable Key is used to enable the MCP as described in Section 6. QLOs only work on parts of the laser system for which they have received OJT and authorization from the SLSO and laser facility program manager. The SLSO and facility manager must be informed of any new beam paths created. Checks for stray beams are performed when alignment is done or when new beam paths are created.

When Green Operation mode is required, the following procedure is used:

i. Close the 2 laser safety shutters. Set the MCP to Green operation mode. Go to the Controlled Entry area and replace the Normal Operation safety glasses with the *Green* glasses (see Section 6 for descriptions of normal and green glasses). Ensure that everyone in the room wears Green glasses.

ii. Remove the necessary covers and enclosures. Bypass cover or enclosure interlocks if needed.

iii. Open the shutters as needed.

iv. Perform necessary alignment work.

v. After the alignment is completed, close the shutters.

vi. Put back the covers and enclosures. Secure them and restore interlocks as needed.

vii. Restore Normal Operation mode and switch to Normal glasses: Change the laser status on the MCP. Go to the Controlled Entry area and replace the Green glasses by the Normal Operation ones. Ensure that everyone in the room wears Normal glasses.

5.2 Hutch 1 Operations in OPEN ACCESS PPS state. The Hutches are also engineered to be production facilities, but they are user facilities supporting a wide range of users from SLAC, universities and other institutions. Many users of the Hutch will not be laser personnel, while some will become QLOs with limited privileges for working on the laser system as determined by the SLSO. To the extent possible, the Hutch will operate in Class 1 mode with the Class 4 laser beams fully enclosed. The LSS Enable Key must enable the MCP for both Class 1 and Class 4 operation in OPEN ACCESS; it is located outside the Hutch at a separate control panel.

For Class 4 operations in the Hutch, the following procedures are followed:

i. Secure the room and prepare for Class 4 operation. The major equipment access must be closed and locked, and the PPS x-ray door must be open. The laser door sliding panel must be closed and secured, and the hinged laser door closed. All personnel present must put on appropriate protective eyewear as described in Section 6.

ii. MCP operations for the LSS. A QLO must badge in using their RFID to access control of the MCP. The Interlock Reset button on the MCP can be pressed to correct any interlock fault. The Class 4 Operation mode on the MCP can then be selected and the shutters can be opened as required. A 15-second audible and visible alarm will sound to warn personnel in the Hutch that laser shutters are about to open. The shutters open at the end of the alarm.

iii. Perform necessary laser work. The interlocked table enclosures can be removed as needed for the work. If further control with the MCP is needed, a QLO will need to badge in again. If an LSS interlock trips during the work, corrective actions as described in Table 4 can be taken.

iv. Restore Hutch for Class 1 operation. Any enclosures that were removed must be replaced. The QLO badges into the MCP and puts the LSS into Class 1 mode. Personnel present may then remove their protective eyewear.

5.3 Maintenance, Service or Repair. Generally this refers to work performed on a commercial laser system or work with a service access panel enclosure removed. The list of QLOs eligible to perform this work is approved by the SLSO. When work is to be done by service subcontractors from a commercial laser company, their work must comply with SLAC's requirements for work by service subcontractors. This includes: a project manager (usually the requisitioner for the work) is assigned; the LSO or their designee provides safety oversight; a buyer administers the contractual arrangements; the project manager provides documentation for the procedure and protective eyewear to be used with a safety analysis for both laser hazards and non-beam hazards; site-specific training is provided for the service subcontractor personnel; and a pre-job briefing meeting is held that includes the project manager, the service subcontractor personnel, and the LSO or their designee. Other requirements for service subcontractor personnel are described in Section 3.4. The SLSO maintains documentation records for service subcontractor work.

When servicing electrical equipment, the equipment must be locked off and tagged according to SLAC lock and tag (LOTO) procedure.

When performing work on equipment associated with the laser beam path (for example, replacing damaged optics or aligning the beam), the LSS and procedures described in the facility SOP generally provide effective protection without the need for LOTO. Special procedures not covered in the SOP may require LOTO, and the LSO is consulted for these as needed.

6. Protective Eyewear

Full protection eyewear is normally required at SLAC for all laser operations whenever a Class 4 laser is enabled. However, certain procedures that have been reviewed, documented and approved by the LSO permit alignment eyewear at reduced optical density (OD). The documentation requires a technical note approved by the LSO that provides a schematic, an alignment procedure, a justification for why reduced OD eyewear is required, and a calculation for the OD to be used for the alignment eyewear. The minimum OD for alignment eyewear must provide protection for diffuse reflections at 0.5-meter viewing distance. Alignment eyewear is only permitted for visible wavelengths, though this can extend beyond the ANSI definition of 700nm to include 800nm.

In the Laser Hall, full protection eyewear is required with OD as specified in Table 1 whenever the LSS Enable Key is used to enable the MCP. For Normal Operation mode, there are no green laser hazards present and eyewear protection is only required for the 800nm laser hazard. The full protection eyewear chosen for Normal Operation (Normal Glasses) is Glendale Filter 300, which has an OD7 rating for 780-830 nm and an EN207 rating for short pulses of M L5; its visual light transmission (VLT) is 45%. In Green Operation mode, eyewear protection for both IR and green laser hazards is required. The full protection eyewear chosen for Green Operation (Green Glasses) is Glendale Filter 123, which has an OD6 rating at 800nm, OD9 rating at 190-532nm and an EN207 rating for short pulses of I,R,M L5 for 532nm; its VLT is 14%. Alignment eyewear at reduced OD is permitted only for special alignment procedures, which are being developed, and will be specified separately.

In Hutch 1, full protection eyewear is required as specified in Table 2 whenever the laser system is in Class 4 operation mode during the OPEN ACCESS PPS state. The full protection eyewear chosen when no harmonics are present (800nm Glasses) is Glendale Filter 300, whose specifications are noted above. When harmonics may be present, then Harmonics Glasses are used for which Glendale Filter 123 (specifications given above) is chosen. Currently, no alignment eyewear procedures are planned for Hutch operations.

References

[1] LCLS information, http://lcls.slac.stanford.edu/.

[2] R. Akre et al., “Commissioning the LCLS Injector,” Physical Review Special Topics – Accelerators and Beams **11**, 030703 (2008).

[3] AMO Experiment information, http://lcls.slac.stanford.edu/amo/.

[4] SLAC Laser Safety Policy information, http://www-group.slac.stanford.edu/esh/hazardous_activities/laser.

Meet the Authors

Michael Woods, CLSO, is the Laser Safety Officer at SLAC. He is an Engineering Physicist with a B.Sc. in Engineering Physics from Queen's University in Kingston, Ontario, Canada and a Ph.D. in High Energy Physics from the University of Chicago. He has spent 15 years as a researcher in experimental particle physics and accelerator physics utilizing high power laser systems. In 2008 he became the LSO at SLAC.

Perry Anthony is a member of the Photon Controls and Data Acquisition Systems Group at SLAC. He is an Engineering Physicist with a B. Sc. in Physics from Oregon State University, and a Ph. D in High Energy Physics from the Massachusetts Institute of Technology. He has spent 15 years designing experiment control and data acquisition systems for experiments at SLAC. From 2004 through 2007 he served as SLAC’s Electrical Safety Officer.

Ken Barat, CLSO, is the Laser Safety Officer at the Lawrence Berkeley National Laboratory. He is chair of the ANSI Z136.8 committee, former LSO for National Ignition Facility Directorate and author of Laser Safety Tools and Training (CRC Press).

Sasha Gilevich is the optical engineer for the LCLS project at SLAC and the System Laser Safety Officer for the LCLS Injector. She received her M.Sc. in Engineering Physics from the St. Petersburg Polytechnic, Russia. Before joining SLAC in 2003 she worked as a laser optical engineer for the laser industry (Spectra Physics, JDS Uniphase) and as a researcher in the field of laser physics for the Vavilov Optical Institute in St. Petersburg, Russia.

Greg Hays is the System Laser Safety Officer for the LCLS Near Experimental Hall at SLAC. He is a Laser Physicist, with a B.S. in Physics from the University of New Mexico and a Ph.D. in Physics from the University of Texas at Austin. He has spent over 19 years as a researcher in short pulse, high-energy laser systems. He joined SLAC in 2007.

William White is the LCLS Laser Group leader at SLAC. He received a B.Sc. and Ph.D. in Physics from Texas A&M University. He has spent half of his career at national laboratories doing research on high-intensity, short-pulse laser systems for AMO, medical, industrial, and plasma physics. The other half of his career has been spent as Vice President or Engineering Manager for Positive Light Inc. and Coherent Inc.