

Chapter 10: [Laser Safety](#)

Class 3B and Class 4 Laser Operation Requirements

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1 Purpose

The purpose of these requirements is to protect workers from harmful exposure to lasers. They cover identifying hazards, developing and implementing controls, and authorizing operations, personnel, and use of Class 3B and Class 4 lasers. They apply to workers using lasers of this classification, *system laser safety officers (SLSOs)*, *laser facility program managers*, line management, ESH coordinators, the *laser safety officer (LSO)*, and Radiation Protection.

2 Requirements

Class 3B and Class 4 lasers have significant potential to cause injury and require specific control measures, described below.

2.1 Approvals

The following approvals must be completed before Class 3B and Class 4 laser operations may begin:

- [Laser Facility Approval](#) for the *location* in which the lasers will be operating. The approval request is submitted by the laser facility's SLSO, who must first affirm that annual laser safety certification checks are complete and that any necessary facility SOP updates are complete. The request must be approved by the facility program manager, the ESH coordinator, and the LSO. LSO approval requires that: 1) the SOP, with any needed revisions, is approved, and 2) a facility inspection has been completed and all pre-approval action items are complete. The LSO approval includes an approval expiration date, which is nominally one year from the approval date.
- A [System Laser Safety Officer Approval Form](#) for the SLSO, who will have line management and supervision responsibilities for safe laser operations in the facility
- A [Acting System Laser Safety Officer Approval Form](#) for the acting SLSO, who performs SLSO functions when the SLSO is not available
- [Laser Worker Approval](#) for the facility's *qualified laser operators (QLOs)*, who will operate these lasers
- [Laser Worker Approval](#) for the facility's *laser controlled area (LCA) workers*, who perform support work such as controls electronics, data acquisition, and accelerator operations

2.2 Engineering Controls

Engineering controls are given first priority over *administrative controls* and *personal protective equipment (PPE)*. Additional engineering controls requirements to those described in this document can be found in the following:

- [Laser Safety: Laser Controlled Area Requirements](#)
- [Laser Safety: Class 3B and Class 4 UV Laser Operation Requirements](#)
- [Laser Safety: Class 3B and Class 4 Laser CoHE Requirements](#)

2.2.1 Removable Covers for Protective Housings, Class 1 Enclosures, and Beam Conduits

Engineering controls for these must meet all of the following requirements:

- Covers that may be removed during *normal operation* or *maintenance* must be provided with *failsafe or redundant interlocks*.
- Covers that are only removed during infrequent service tasks must either
 - Be interlocked (failsafe or redundant interlocks not required) or
 - Be secured, requiring a tool to remove
- If defeatable interlocks are used, it must not be possible to replace the cover with the interlock defeated.
- In uncontrolled areas, non-defeatable cover interlocks must be used for *Class 1 enclosure* or *beam conduit* covers that may be removed to enable Class 3B or Class 4 work, except if LSO approval is given to use an administrative configuration control lock.

Engineering controls for these should include each of the following:

- Interlocked covers for SLAC-built lasers if similar commercial lasers would have them because removing the cover exposes a different wavelength hazard
- Interlocks for Class 1 enclosure covers that are frequently removed or may be removed for an extended period, and may expose a different wavelength hazard when removed
- An engineered *laser safety system (LSS)* configured so it is easy to add a new Class 1 cover interlock
- Redundant cover interlocks, if used in an uncontrolled area

Note *Interlocked cover controls provide a higher level of engineering control than secured covers; and non-defeatable interlocks provide a higher level of engineering control than defeatable interlocks.*

2.2.2 Removable Connectors for Fiber Transport Cables

Removable connectors must either be

- Interlocked, so the laser source is disabled when in the disconnected state, or
- Secured, requiring a tool to disconnect, unless the connector is within a secured or interlocked enclosure

2.2.3 Exclusion LCAs and Walk-in Protective Housings

Engineering controls for these must include

- Failsafe or redundant access control interlocks to disable laser hazards in excess of Class 3R if a person enters
- An electronic warning device at the entry to the LCA or walk-in protective housing that indicates a NO ACCESS condition.

Note Exclusion LCAs and walk-in protective housings have engineered controls to ensure no persons are inside the LCA with Class 3B or Class 4 laser beams enabled.

2.2.4 Barriers, Beam Path Control, and Beam Termination

Appropriate *barriers*, beam path control, and beam termination are needed to block potential stray beams and prevent accidental placing of objects or parts of one's body in a beam path.

Engineering controls for these must include the following:

- Backstops behind the upper turning mirror in a periscope if there is an upward-going beam
- Beam barriers to contain possible stray beams from optics that can generate out-of-plane beams (for example, periscopes, beam-splitting polarizers, corner cubes, retroreflectors, and diffraction gratings)
- Appropriate beam termination for all primary and stray beams

Engineering controls for these should include the following:

- Backstops behind turning mirrors if other barriers are not adequate to contain stray beams
- Table skirts at the perimeter of laser tables (these are barriers that extend 1 to 2 inches above the nominal height of laser beams on the table)

2.3 Procedures

2.3.1 Lab-specific Standard Operating Procedure

Each *laser controlled area (LCA)* or *laser facility* must have an associated *standard operating procedure (SOP)* and *laser safety contract*, described in a document referred to as the *lab-specific SOP*. This document identifies potential hazards present and describes controls to mitigate these hazards.

Note Generally, a laser facility has one or more LCAs; a facility approved only for fully enclosed Class 1 operation will have no LCAs. In most cases a single lab-specific SOP will cover all the facility's LCAs; in others each LCA will have its own.

The lab-specific SOP usually references a general SOP, [General Laser Laboratory Safety for SLAC QLOs and LCA Workers](#). This document describes hazards and controls that are broadly applicable to Class 3B and Class 4 laser laboratories at SLAC, many of which use a SLAC-built *laser safety system (LSS)* found in most accelerator, Linac Coherent Light Source (LCLS), and research laser labs.

The general and lab-specific SOPs have minimal overlap and requirements in both apply, though the lab-specific SOP takes precedence if there is a conflict.

The lab-specific SOP must include the following:

- Reference to the general SOP, if applicable
- Schematic of the laser facility, which includes identifying the *nominal hazard zone (NHZ)*. The NHZ is the area inside the LCA where there may be accessible laser radiation above the *maximum permissible exposure (MPE)* when lasers are enabled.
- Lasers and laser system specifications
- Laser hazard parameters and associated *optical density (OD)* requirements for laser eyewear
- Engineered LSS and other engineering controls
- Description of the laser operation modes and associated eyewear requirements
- Lab-specific non-beam hazards
- Laser eyewear specifications
- Lab-specific training
- Administrative procedures, including
 - How to set each operation mode (for example, Laser Off, Class 1, Class 4) and any operation mode requirements such as restrictions on unattended Class 1 operation
 - Special or non-routine alignment procedures that have requirements that go beyond what is described in core laser safety practices (for example, during optical parametric amplifier [OPA] alignment)
 - Special requirements if more than one type of laser eyewear protection is used in Class 4 mode. Different eyewear requirements should have different Class 4 operation modes defined.
 - Special requirements for laser maintenance or service work
 - Entry and egress procedure during Class 4 operation

The general SOP document describes the following administrative controls:

- Reference to following core laser safety practices (see [Laser Safety: Core Laser Safety Practices](#))
- How to respond if there is a failure in an LSS component
- Requirements for pre-job briefings
- Requirements for safety configuration control, including for moving safety shutters or other key safety components
- Requirements for satisfying *control of hazard energy (CoHE)* to prevent the unexpected startup or energization of a laser hazard (see [Laser Safety: Class 3B and Class 4 Laser CoHE Requirements](#))

Lab-specific and general SOP documents do not have expiration dates unless specifically indicated. A template for lab-specific SOPs is available on the [Laser Safety Program Site](#).

2.3.2 Job Safety Analysis

A *job safety analysis (JSA)* is sometimes used to extend the description of laser hazards and controls given in a lab-specific SOP. For example, it may be used when a particular experiment is being done that is short-lived and it does not make sense to revise the SOP, or it may be used for specialized procedures that only a few of the facility's QLOs will perform.

JSA approval includes an expiration date. Sample JSAs are available on the [Laser Safety Program Site](#).

2.3.3 Configuration Control Form

Actions that modify the safety configuration or function of a Class 1 enclosure, a safety shutter, or a component of the engineered LSS require a configuration control change process to be followed, resulting in an approved *configuration control form (CCF)*. Use of a CCF should be described in the lab-specific SOP or JSA, but may also be used as a standalone procedure document if approval is given by the LSO.

Note Some simple actions that are adequately described in an SOP or JSA may be exempt from this requirement. Consult the LSO on such exemptions.

Example actions that would require a CCF are

- Changing a Class 1 enclosure in any manner that changes its safety function
- Relocating a safety shutter or interlocked laser power supply (except for very simple changes if LSO approval is given)
- Bypassing any required laser safety interlock (except for defeatable interlocks if used as described in the SOP)
- Re-starting laser operations for portable laser systems following a change in location or following a long period of non-use.
- Applying or removing a configuration control padlock

The CCF must include the following information:

- Description of action to be performed and its purpose
- Safety requirements and certification checks needed before starting the action
- Safety requirements and certification checks needed while laser system is in a modified state; when laser system is in a modified state, a copy of the CCF must be posted, preferably at the laser control panel and/or laser entry door
- Safety requirements and certification checks needed to restore normal laser operations
- Names and dates for persons performing the work and safety checks, together with their signatures or initials.

The person performing the work is responsible for completing the form. The SLSO approves the CCF description and completion of work under the CCF and determines additional notifications. LSO notification of CCF use is required; work under a CCF requiring an LSO inspection requires LSO approval (the LSO determines whether an inspection is required after reviewing the notification).

A recommended CCF template is available on the [Laser Safety Program Site](#).

2.3.4 Annual Inspections by the LSO

Annual inspections of Class 3B and Class 4 LCAs must include the following:

- Verification that the current SOP document(s) accurately reflects current laser operations
- Verification that laser system interlock functionality checks have been completed
- Review of the list of authorized laser workers, and verification that their training is current
- Review of lasers in use and verification that their operations are adequately described in the SOP (and JSA) document(s)
- Verification that LCA entryway postings meet requirements
- Inspection of eyewear and eyewear storage location to verify that requirements are met, including that the eyewear is not damaged and that only approved laser eyewear is present
- Checking that barriers and beam containment are adequate
- Checking that housekeeping is adequate
- Review of status of open action items from last inspection

2.3.5 Laser Worker Approval

Laser workers, both qualified laser operators (QLOs) and laser controlled area (LCA) workers, must complete formal and on-the-job training and a medical exam and be approved by the LSO, his or her administrative supervisor or point-of-contact (POC), and the SLSO (if applicable) before beginning work with Class 3B and Class 4 lasers.

See the [Laser Safety: Laser Worker Approval Procedure](#).

2.4 Equipment Labels

Templates for equipment labels are available on the [Laser Safety Program Site](#).

2.4.1 Protective Housings

An equipment label must be affixed to a conspicuous place on the housing and provide hazard information for the output laser beam (class, wavelength, pulse duration if appropriate, maximum power and appropriate WARNING or DANGER signal word).

An equipment label must also be placed on the control panel if it is separated from the housing by more than 2 meters.

If there is an output aperture, there should be an associated aperture label.

2.4.2 Removable Covers on Protective Housings and Class 1 Enclosures

A warning label identifying the highest class of laser radiation contained within the enclosure or housing must be affixed to each removable cover. The label must include the following text (or equivalent):

- If the cover has no defeatable interlocks
 - CLASS 3B LASER RADIATION WHEN OPEN or
 - CLASS 4 LASER RADIATION WHEN OPEN
- If the cover has defeatable interlocks
 - CLASS 3B LASER RADIATION WHEN OPEN AND INTERLOCKS DEFEATED or
 - CLASS 4 LASER RADIATION WHEN OPEN AND INTERLOCKS DEFEATED

2.4.3 Removable Fiber Connectors

A warning label identifying the highest class of laser radiation contained within the fiber must be affixed to each removable fiber connector. The label must include the warning statement (or equivalent):

- HAZARDOUS LASER RADIATION MAY BE ACCESSIBLE WHEN DISCONNECTED

2.4.4 Long-distance Beam Conduits and Fiber Transport

On long-distance beam conduits and fiber transport, a warning label must be placed approximately every 3 meters. The label text must include a WARNING or DANGER signal word and the following text (or equivalent):

- CLASS 3B LASER RADIATION ENCLOSED or
- CLASS 4 LASER RADIATION ENCLOSED

2.5 Unsupervised and Unattended Laser Operation

2.5.1 Unsupervised Laser Operation

Unsupervised laser operation is not permitted.

Note *Unsupervised laser operation would be operation of a Class 3B or Class 4 laser without authorization from an assigned SLSO, which is not permitted per the requirements in Section 2.1.*

2.5.2 Unattended Laser Operation

Class 3B and Class 4 lasers or laser systems that are only used as part of a LSO-approved Class 1 laser system are exempt from the requirements in this section.

The unattended use of Class 3B or Class 4 lasers or laser systems is permitted only when these conditions are met:

- The SLSO has ensured that control measures, consistent with the hierarchy of controls, provide adequate protection to those who may enter the LCA during times of unattended use.

The SOP, or JSA if applicable, does not prohibit unattended operation. Note *The engineered LSS for many SLAC laser facilities permits unattended laser operation, with an associated door interlock bypass capability whose functionality is described in the SOP.*

Requirements for engineering controls for LCA entryways (for example, locked and interlocked door) are described in [Laser Safety: Laser Controlled Area Requirements](#).

2.6 Training

SLSOs have line management responsibility for providing and documenting *on-the-job training (OJT)* to QLOs and LCA workers. This includes the SLSO maintaining an OJT syllabus for site-specific training for each worker. The SLSO must conduct an annual refresher for this training.

A template for an OJT syllabus is available on the [Laser Safety Program Site](#). SLSOs use this to develop a facility's syllabus, which is posted on the facility SharePoint. The [Laser Safety Tool](#) is used to document annual OJT in a "Laser Worker Summary" table and specific work authorization in an "OJT Summary" table.

2.7 Control of Hazardous Energy (CoHE)

CoHE requirements prevent the accidental startup or energization of energy sources. See

- [Laser Safety: Class 3B and Class 4 Laser CoHE Requirements](#)

2.8 Laser Eyewear Protection

When using Class 3B or Class 4 Lasers, the following requirements must be met:

- [Laser Safety: Class 3B and Class 4 Laser Eyewear Protection Requirements](#)

2.9 Safety Evaluation of Non-beam Hazards

Non-beam hazards result from factors other than direct human exposure to a laser beam but are associated with laser equipment or laser operations. Non-beam hazards include

- Electrical (laser power supplies, high voltage connections)
- Fire and explosion (flammable solvents in dye lasers, high pressure arc lamps, capacitor banks). (Fire safety is particularly important for Class 4 lasers; requirements are described in the following Section 2.10.)
- Chemicals
- Pressure vessels
- Compressed gases
- Cryogenics
- Mechanical (associated with robotics)
- Collateral radiation (x-rays from electrical equipment operating above 15 kV, or ultraviolet (UV) radiation from flashlamp operation)
- Hazards from laser-target interactions (laser-generated air contaminants, combustion of flammable materials, plasma radiation, and, at very high irradiance, ionizing radiation).

The SLSO, laser facility program manager, and ESH coordinator are responsible for appropriate evaluation of and safety controls for non-beam hazards and all non-laser safety issues. Evaluation and safety controls for non-beam hazards must be described in the lab-specific SOP or in a JSA.

The LSO will assist in evaluating hazards and controls for non-beam hazards and consult with other ESH program managers and subject matter experts as needed.

2.9.1 Safety Evaluation of Ionizing Radiation Hazard from Laser-Target Interactions

Review by SLAC's Radiation Protection Department is required for the following laser operations:

- Laser beam is focused to intensities $> 10^{15}$ W/cm², or
- Laser beam is focused to intensities $> 10^{13}$ W/cm², if all the following conditions are also met:
 - Laser beam average power > 0.5 W
 - Focused beam is or may be incident on a *renewable* solid or liquid target
 - Focused beam is not enclosed in a vacuum chamber or pressure vessel

The target is considered *renewable* if

1. The laser beam is rastered or otherwise moved on a solid target, or
2. A solid target is rastered or otherwise moved during laser beam exposures, or
3. The laser beam is incident on a liquid target

At the high intensities capable of generating an ionizing radiation hazard, the laser beam will ablate a solid target and in this situation the radiation hazard will not be sustainable unless the target is renewable. (For example, an accident scenario that results from a high intensity focused laser beam mis-steered onto a barrier would not produce a sustainable radiation hazard.)

2.10 Fire Safety Requirements

Fire prevention control measures must be implemented for all Class 4 lasers and for all lasers with average beam irradiance of 0.5 W/cm² or greater. These controls must include all of the following:

- Minimize combustible materials.
- Route and secure cables and plastic tubing carefully so they cannot be exposed to a laser beam.
- Use appropriate materials for beam dumps, shutters, and barriers. For high average power laser hazards ($> \sim 100$ W), water-cooled shutters and beam dumps may be needed. Perform damage and acceptance tests for beam dumps and shutters as applicable.
- Verify correct placement, securing, and beam alignment for shutters and beam dumps.
- Ensure portable fire extinguishers are accessible within 75 feet.
- Ensure an emergency shutdown switch is located near the laser equipment. The EMERGENCY OFF button described in [Laser Safety: Class 3B and Class 4 Laser Controlled Area Requirements](#) can be used for this.

- Annual OJT on fire hazards and controls for all QLOs and LCA workers, including the following:
 - Locations for fire alarms and fire extinguishers
 - Emergency entry and egress
 - Emergency Off
 - Response to a fire:
 - Perform Emergency Off if practical, and exit area
 - Ensure someone calls 911 or pulls a fire alarm
 - Only use fire extinguisher if all of the following are satisfied: fire is small and is not growing quickly; [ESH Course 108](#) is current; and the fire extinguisher is the correct type.
 - Notify supervisor and the area or building manager.

Note Additional guidance on fire safety for laser systems can be found in [NFPA 115](#).

Additional controls are needed for laser equipment utilizing flammable or reactive gases, or ignitable liquids. The ESH coordinator, fire marshal, and LSO must be informed if these are used.

2.11 QLO and LCA Worker Service Work in Laser Labs

Generally, a QLO or LCA worker may only work in the facility for which he or she has been approved. However, a QLO or LCA worker may enter and work in another laser facility without becoming a QLO or LCA worker for that facility in order to perform short-term *service* work, measurements, or experiments, subject to the following conditions:

- The visiting QLO or LCA worker, called a *service QLO* or *service LCA worker*, must have approval from his or her administrative supervisor and the SLSO (or their designees) for the laser facility being visited.
- The visiting service QLO/LCA worker must be escorted by one of the facility's QLOs or LCA workers.
- There must be a pre-job briefing between the service QLO/LCA worker and the escorting QLO/LCA worker for the work to be performed.

Unescorted work in Class 4 mode may only be done by the laser facility's own QLOs/LCA workers.

Note SLSOs should minimize the number of QLOs approved for a specific laser facility by taking advantage of this service QLO (and LCA worker, described below) designation.

2.12 Laser Controlled Area Worker

Laser controlled area (LCA) workers perform support work such as controls electronics, data acquisition, and accelerator operations. To do so they receive limited approval to be allowed access to laser facilities. They have the same responsibilities as QLOs but are not authorized to perform laser alignment work, and, depending on the facility, may be restricted from changing operation mode or opening shutters.

SLSOs should implement the following controls for these workers:

- Limit their number to only those that are essential and may need unescorted laser facility access.
- Limit their scope of work, including limiting radio-frequency identification (RFID) authorization for the laser safety control panel.
- Conduct periodic refresher OJT.
- Conduct pre-job briefings prior to their laser work and determine if their work needs to be supervised by a regular QLO.
- Determine if any additional LCA or NHZ controls are needed to accommodate their work.
- Avoid scheduling their work during Class 4 laser operations, in particular if laser alignment will be taking place.

2.13 Laser Controlled Area Visitor Policy

Laser controlled area visitors are personnel who have not been approved as a QLO/LCA worker in a SLAC laser facility. (This does not include service subcontractors or the LSO). Visitor access when Class 3B or Class 4 lasers may be in operation is strongly discouraged but may be allowed if adequate controls are present. For requirements see [Laser Safety: Laser Controlled Area Visitor Requirements](#).

3 Forms

The following are forms required by these requirements:

- [Laser Facility Operations Approval](#). Documents approvals for Class 3B and Class 4 laser facility operations
- [Laser Worker Approval](#). Documents approvals for QLOs and LCA workers
- [Laser Safety: System Laser Safety Officer Approval Form](#) (SLAC-I-730-0A05J-001). Documents approvals for SLSOs
- [Laser Safety: Acting System Laser Safety Officer Approval Form](#) (SLAC-I-730-0A05J-009). Documents approvals for acting SLSOs
- Site-specific training documentation for QLOs and LCA workers. A template for an OJT syllabus is available on the [Laser Safety Program Site](#) (SharePoint). SLSOs use this to develop a facility's syllabus, which is posted on the facility SharePoint. The [Laser Safety Tool](#) is used to document annual OJT in a "Laser Worker Summary" table and specific work authorization in an "OJT Summary" table
- Lab-specific SOP, JSA, and CCF documents: templates and examples for these are available on the [Laser Safety Program Site](#) (SharePoint).

4 Recordkeeping

The following recordkeeping requirements apply for these requirements:

- The SLSO must maintain the following records for the laser facility to which he or she is assigned:
 - Lab-specific SOP, and any supplemental JSAs or CCFs in use
 - SLSO/acting SLSO approval forms

- OJT documentation for the facility’s QLOs and LCA workers
- Inventory of lasers, laser keys, and keys issued to QLOs
- Alignment eyewear approval forms and log forms, if alignment eyewear is used
- Documentation for tests and certification of the LSS
- Documentation for audits and facility reviews, such as the annual laser safety inspection conducted by the LSO
- Worker and facility approval records are maintained in the [Laser Safety Tool](#)
- All current safety documentation records must be available as:
 - Printed copies in the laser safety binder at the laser facility, or
 - Electronically accessible on the [Laser Safety Program Site](#) or in the [Laser Safety Tool](#).

5 References

[SLAC Environment, Safety, and Health Manual](#) (SLAC-I-720-0A29Z-001)

- [Chapter 10, “Laser Safety”](#)
 - [Laser Safety: Laser Worker Approval Procedure](#) (SLAC-I-730-0A05C-003)
 - [Laser Safety: Class 3B and Class 4 UV Laser Operation Requirements](#) (SLAC-I-730-0A05S-012)
 - [Laser Safety: Class 3B and Class 4 Laser CoHE Requirements](#) (SLAC-I-730-0A05S-005)
 - [Laser Safety: Laser Controlled Area Requirements](#) (SLAC-I-730-0A05S-009)
 - [Laser Safety: Class 3B and Class 4 Laser Eyewear Protection Requirements](#) (SLAC-I-730-0A05S-007)
 - [Laser Safety: Core Laser Safety Practices](#) (SLAC-I-730-0A05S-006)
 - [Laser Safety: Laser Controlled Area Visitor Requirements](#) (SLAC-I-730-0A05S-011)
 - [General Laser Laboratory Safety for SLAC QLOs and LCA Workers](#) (SLAC-I-704-701-003-00)
 - [Laser Safety Program Site](#) (SharePoint)
 - [Laser Safety Tool](#)

Other SLAC Documents

- [On-The-Job \(OJT\) Training Requirements \(200-2P-1\)](#)
- ESH Course 108, Fire Extinguisher Training ([ESH Course 108](#))

Other Documents

- National Fire Protection Association (NFPA) 115, “Standard for Laser Fire Protection” ([NFPA 115](#))