Guidance on Laser Safety Requirements

for Hazard Evaluation, Control Measures, Training and Laser Safety Programs

DOE EFCOG Laser Safety Community of Practice

Revision Record

Revision	Date	Description of Change
R000	August 5, 2019	Original release
R001	February 13, 2023	Added following sections: • 2, Hazard Evaluation • 2.1, Risk Assessment • 3.1, General Considerations • 3.2, Hazard Control Hierarchy • 3.5.4, Configuration Control • 3.7, Signs and Labels • 3.8, Special Topics • 3.8.1, Controls for High Power Lasers, High Pulse Energy Lasers and Laser Systems with an Ionizing Radiation Hazard • 3.8.2, Controls for Class 1 lasers with embedded Class 3B, Class 4 lasers • 3.8.3, Laser Transport between Two LCAs • 3.8.4, Laser Manufacturer Requirements and FDA Compliance • 5.2, Examinations Following a Suspected or Actual Laser-Induced Injury • Appendix A.1, Example Laser Hazard Parameters Table • Appendix A.2, Example FMEA • Appendix A.3, Example Risk Matrix Removed 5.2, Baseline Eye Exam Added following definitions: Credited Controls, Failure Mode and Effects Analysis (FMEA), Hazard Analysis, Incident, Interlock, Laser Component, Laser Product, Optical Density, Risk, Safety Envelope, Transmittance

Contents

Acronyms

AEL	accessible emission limit
ANSI	American National Standards Institute
DOE	United States Department of Energy
EFCOG	(DOE) Energy Facility Contractors Group
FMEA	Failure Mode and Effects Analysis
LCA	laser controlled area
LSCP	(DOE EFCOG) Laser Safety Community of Practice (note: formerly Laser Safety Task Team)
LSO	laser safety officer
MPE	maximum permissible exposure
NHZ	nominal hazard zone
OD	optical density
OJT	on-the-job training
PLC	programmable logic controller
PPE	personal protective equipment
SIL	safety integrity level
SIS	safety interlock system
SOP	standard operating procedure

Definitions

Administrative control. Control measure that administratively mitigates the potential hazards associated with laser use. For example, training, safety approvals, LSO designation, signs, labels and SOPs.

Administrative Supervisor. Person a laser worker reports to and who is responsible for determining the worker's training requirements.

Alignment Eyewear. Protective eyewear for visible wavelengths with a reduced optical density (OD) from full protection.

Alignment Training. A hands-on laser beam alignment course and/or alignment training specific to the lasers used

Alternate controls. Control measures that take the place of explicitly specified control(s) in this document.

Barrier. A device used to block or attenuate laser radiation.

Beam conduit. Used to transport a laser beam between two locations.

Class 1 Condition. Accessible laser radiation levels during operation are at or below applicable MPE levels.

Class 1 enclosure. An enclosure that surrounds a laser or laser system and prevents access to laser radiation levels above the MPE from the enclosed laser or laser system

Controls hierarchy. Engineering controls are first line of defense, followed by administrative controls, and then the last line of defense is PPE.

Cover Interlocks for Class 1 Enclosures and Protective Housings. When the cover of a Class 1 enclosure or a protective housing is removed, this interlock disables any additional accessible Class 3B or Class 4 laser hazard(s) to below the MPE.

Credited Control. A control determined via a risk assessment that is required to reduce risk to an acceptable level.

Defeatable interlock. A mechanism that allows for the bypassing of the interlock feature when a cover/panel is removed for special operations (e.g., laser alignment or maintenance).

Deputy LSO. Has the same authority as the LSO for operation and approval of assigned lasers and laser facilities.

Emergency Stop (OFF) Device. When activated, this ensures any laser radiation within the LCA is below the Class 3R accessible emission limit (AEL).

Enclosure. Surrounds a laser or laser beam and prevents access to laser radiation inside it. (e.g., protective housings, Class 1 enclosures, beam conduits and fiber transport)

Engineering control. Control measure designed or incorporated into the laser or laser system (for example, interlocks, shutters, enclosures, key controls).

Equivalent Protection. Provides the same level of risk mitigation to prevent injury.

Exclusion mode for an LCA. When an LCA uses engineered controls to ensure no persons are inside the LCA with Class 3B or Class 4 laser beams enabled.

Failsafe or redundant interlock. Interlock that does not permit an unsafe condition if there is a single component

failure.

Failure Mode and Effects Analysis (FMEA). A method to determine all possible failure modes in a design, product or service; to determine the consequences of those failures; and to determine what controls are required.

Fiber Transport Cable. An optical cable used to transport a laser beam between two locations.

Full Protection Eyewear. Protective eyewear that attenuates the laser beam to a safe level below the MPE.

Hands-on Training. Practical training where personnel learn and demonstrate how to operate equipment and use it for the intended application. The equipment may be similar, but not identical, to equipment in the work environment. This training takes place in the LCA or in a simulated work environment.

Hazard Analysis. A rigorous process of analyzing the probability and consequences from a condition or event, and determining the potential impact. A hazard analysis provides a basis to select controls for mitigating hazards.

Incident. An off-normal event involving laser operations or laser equipment that has the potential to cause a hazardous laser exposure or other injury.

Interlock. Engineering control that makes the state of two systems, or functions, mutually dependent. A laser safety interlock detects a fault condition that increases risk for exposure to hazardous laser radiation, and takes action to mitigate that increased risk.

Laser. A device that produces radiant energy predominantly by stimulated emission. Laser radiation may be highly coherent temporally, spatially, or both. An acronym for Light Amplification by Stimulated Emission of Radiation.

Laser component. Device used in a laser product that is not capable of producing laser radiation.
Informational Note: an example would be a laser head with no power source or an OPA

Laser controlled area (LCA). An area within which potentially hazardous beam exposure from a Class 3B or Class 4 laser is possible. Access and/or occupancy of the area are controlled. This area may be defined by walls, barriers, or other means.

Laser facility (laser lab). A work area where a Class 3B or Class 4 laser may operate. It may have one or more LCAs, but may also have no associated LCA if it is engineered and approved for fully enclosed Class 1 operation.

Laser product. Any manufactured product or assemblage of components which constitutes, incorporates, or is intended to incorporate a laser or laser system. A laser or laser system that is intended for use as a component of an electronic product shall itself be considered a laser product.

Laser Safety Officer (LSO). One who has authority and responsibility to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards. For the purpose of this document, the LSO is the site-wide LSO with responsibility for the laser safety program at the DOE site.

Laser Source Beam Stop/Attenuator. Prevents access to the source's laser radiation in excess of applicable MPE.

Laser Supervisor. One who is assigned authority and responsibility to supervise Class 3B and Class 4 laser operation and associated use of them by laser workers.

Laser System. An assembly of electrical, mechanical, and optical components that includes a laser.

Laser Worker. Individuals who are trained and authorized to work with, or have the potential for exposure to, greater than Class 3R laser radiation.

LCA Warning Device. Electronic illuminated indicator that displays when laser radiation above Class 3R AEL may be present within the LCA.

Maintenance operation. Performance of those adjustments or procedures (specified in the user information provided by the manufacturer, and considered preventative, to maintain optimal performance of the laser system), which are to be carried out by the user to ensure the intended performance of the product. Interlocked covers for protective housings and Class 1 enclosures may be removed for maintenance tasks.

Master key. A device (typically a mechanical key) that when removed prevents associated laser(s) from emitting laser radiation above the MPE.

Maximum permissible exposure (MPE). The level of laser radiation to which an unprotected person may be exposed without adverse biological changes in the eye or skin.

Nominal Hazard Zone (NHZ). The space within which the level of the direct, reflected, or scattered radiation may exceed the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the applicable MPE.

Non-beam Hazards. All hazards arising from the presence of a laser system, excluding direct human exposure to direct or scattered laser radiation.

Non-defeatable Interlock. Contains no means to bypass the interlock feature and is always active.

(Normal) Operation. The performance of the laser or laser system over the full range of its intended functions. Removable covers for protective housings and Class 1 enclosures are in place.

Informational Note: alignment tasks can be performed during (normal) operation.

On-the-Job Training (OJT). OJT takes place in a specific LCA where instructions on laser operation and laser safety are given. Instruction may also include, as needed, laser alignment and experimental procedures.

Optical Density (OD). The logarithm to the base ten of the reciprocal of the transmittance at a particular wavelength: $D(\lambda) = \log10 [1/\tau(\lambda)]$, where $\tau (\lambda)$ is the transmittance at the wavelength of interest

Personal Protective Equipment (PPE). Personal safety protective devices used to mitigate hazards associated with laser use (e.g., laser eye protection, protective clothing, and gloves).

Protective Housing. An enclosure that surrounds the laser or laser system and prevents access to laser radiation levels above the MPE, except for the output beam. A protective housing does not include the aperture for the output beam.

Removable Cover. A cover for a laser's protective housing or Class 1 enclosure that may be removed to perform tasks with the laser's hazards enabled.

Remote interlock connector. Part of a laser source that interfaces with an LCA's safety interlock system (SIS). When the connector contacts are open or faulted, the laser source is disabled from emitting laser radiation above the MPE.

Risk. The combination of the probability of an event and the consequence from that event that determines the potential impact of the event. Risk is determined from analysis of the probability and consequence, using some rigorous and defined hazard analysis process.

Safety Envelope. The set of engineered and administrative bounding conditions within which a system or process may be safely operated with acceptable risk. The safety envelope is comprised of control systems and operating parameters. The safety envelope is generally established through a hazard evaluation process.

Safety shutter. A remotely controlled beam block that can be inserted to function as a machine guard (or sometimes as an energy isolating device in a LOTO procedure). It is often used to disable a laser hazard as part of an

interlocked access control. It is also sometimes used in an LCA as part of a Class 1 enclosure if it is closed and disabled.

Safety Interlock System (SIS). A combination of devices and logic systems that are used at LCAs for access control, warning systems, permissives and/or control for safety shutters and laser power supplies.

Service. The performance of procedures, typically defined as repair, to bring the laser or laser system or laser product back to full and normal operational status. Service does not include operation or maintenance as defined in this section. Non-interlocked covers for protective housings, Class 1 enclosures and Beam Conduits may be removed for service tasks.

Shall. Mandatory

Should. Advisory (Recommended)

Skin Exam. This includes: observation of dermatological abnormalities, history of skin problems, current complaints of skin problems, and use of potentially photosensitizing drugs.

Skin PPE. Skin protection that reduces skin exposure to levels below the MPE.

Standard Operating Procedure (SOP). Formal written description of the safety and administrative procedures to be followed in performing a specific task.

Transmittance (τ). The ratio of the transmitted power (energy) to incident power (energy).

Unattended Laser Operation. Operation of a Class 3B or Class 4 laser when no laser workers with authorization for that laser are present at the laser location or its associated laser controlled area.

Unsupervised Laser Operation. Operation of a Class 3B or Class 4 laser without authorization from an assigned laser supervisor.

Walk-in Protective Housing. See Exclusion mode for an LCA.

1. Introduction

1.1. Purpose

This document:

- *provides guidance for laser safety policy requirements*
- *provides guidance on how to incorporate requirements in ANSI Z136.1 and other application-specific Z136 standards into laser safety programs. The Control Measures' requirements contained within are written so that they can easily be used in DOE site laser safety manuals*
- *assists harmonization of best laser safety practices*
- *should not be viewed as an attempt to set policy as this is left up to each of the individual contractor operated Laboratories and their DOE oversight*

This document does NOT address all of the laser safety policy requirements needed for a DOE site's laser safety program. Rather, it addresses those which have been reviewed by the DOE-EFCOG LSCP to date. It will be updated as additional requirement topics are addressed.

1.2. Applicability

The guidance provided in this document applies to all Class 3B and Class 4 laser operations at DOE sites and to all workers who design, build or test Safety Interlock Systems for these operations.

Requirements recommended in this report are at least as stringent as in ANSI Z136.1-2014. Z136.1-2014 has many requirements that are "*should*" for Class 3B and "*shall*" for Class 4. This report generally makes the requirements "*shall*" for both Class 3B and Class 4. Alternate controls can be used though, if approved by the LSO, in certain applications such as <20 mW continuous wave (cw) visible lasers or configurations with very simple beam delivery and stable configuration. Alternate controls may include one or more of the following: no unattended operation, simple beam paths and perimeter barriers, and no out-of-plane beams.

This report generally assumes a DOE site with a laser program as follows:

1. more than one Class 3B or Class 4 LCA
2. LCAs often have more than one Class 3B or Class 4 laser
3. a typical laser lab, for which this report is primarily based, is shown below in Figure 1-1 and Figure 1-2. It has:
    a. a contained indoor LCA (enclosed within a room)
    b. a single entrance
    c. a SIS with an access control panel at the entrance
    d. all lasers located within the LCA

1.3. Policies and Standards

This document meets the requirements of the following:

- *American National Standard for Safe Use of Lasers, Z136.1-2014*

Figure 1-1. The Laser Controlled Area (LCA) is bounded by four walls. On the front wall is the entry door with an associated laser hazard sign and an electronic laser status warning device.

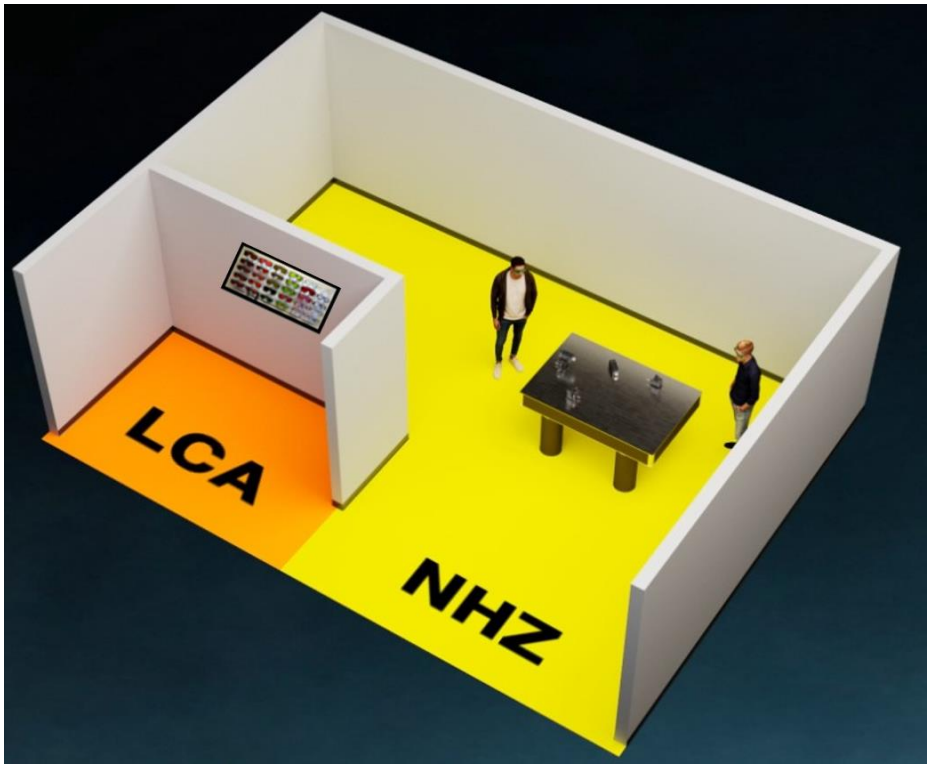

Figure 1-2. The LCA is shown with the front wall removed. The Nominal Hazard Zone (NHZ) within the LCA is denoted in yellow. The orange part of the LCA near the entry is protected by a barrier wall and is considered a "safe" location outside the NHZ where one would put on or remove laser protective eyewear and any other required PPE.

2. Hazard Evaluation

Factors that influence the laser hazard evaluation include:

a. The laser or laser system's capability to injure personnel or interfere with task performance,
b. The environment in which the laser is used, including access to the beam path,
c. The personnel who may use or be exposed to laser radiation.

Specific factors *shall* include:

a. Laser beam characteristics for all lasers present in the lab, including: wavelength, average power, classification and, if applicable, beam pulse parameters (pulse energy, pulse width, repetition rate)
b. Laser eyewear optical density requirements for all accessible wavelengths

See Appendix A.1 for an example that has a table of laser beam characteristics and associated eyewear OD requirements.

Additional factors *should* include, as appropriate:

a. Configuration of the lasers and laser beam paths
b. Other equipment integrated with the lasers and laser systems (e.g., power sources, vacuum chambers, pressure vessels)
c. Laser-target interactions, which can produce additional non-ionizing and ionizing radiation, as well as laser-generated air contaminants
d. Skin exposure (e.g., additional consideration for beam containment and PPE for UV or high-power laser operations)

2.1. Risk Assessment

2.1.1. Requirements

Risk assessment criteria *should* be incorporated into each DOE site's laser safety program. A "risk matrix" approach *should* be followed.

2.1.2. Applicability

Laser hazard evaluations *should* incorporate a risk assessment when:

a. laser average power > 100 W, or
b. laser pulse energy > 10 J, or
c. laser beam is transported from one LCA to another LCA, or
d. laser is focused on a target with a high peak intensity and the hazard evaluation determines an ionizing radiation hazard may exist. This can occur when:
    i. focused peak intensity > 10^{15} W/cm^2 on a target, or
    ii. focused peak intensity > 10^{13} W/cm^2 and all the following conditions are also met:
        - laser beam average power above ~0.5 W
        - focused beam is incident on a renewable solid or liquid target
        - focused beam is not enclosed in a vacuum chamber or pressure vessel

2.1.3. Methodology

An LSO *shall* perform a risk assessment, when applicable, using a method that adequately identifies all hazards and controls associated with the tasks/activities. The methodology *should*:

a. Identify the system, location, and scope of work (be specific).
b. Identify the tasks. Incorporate both routine activities and non-routine activities (alignment, service, maintenance, repair, replacement, etc.).
c. Evaluate potential hazards and include possible failure mechanisms if a component or safety control fails or a laser worker makes a procedural error. An FMEA method is often employed for this (see Appendix A.2 for an example).
d. Identify the existing control measures, including those that will be implemented prior to performing the tasks.

e. Evaluate the probability and consequence of an incident, taking into account the existing control measures. Then use an appropriate risk matrix (see example in Appendix A.3) to assign the risk level.
f. Use the risk matrix result to determine if the risk level is acceptable.
g. **If the risk level is unacceptable**, then
    i. Determine what additional control measures need to be implemented.
    ii. Re-evaluate the probability and consequence of an incident, taking into account the additional control measures.
    iii. Use the risk matrix to determine if the updated risk level is acceptable.
    iv. Continue iterating this step until the mitigated risk level is acceptable.
h. Ensure that laser SOP(s) or appropriate laser work control document(s) include descriptions of tasks, hazards and the control measures required to achieve an acceptable risk level.
i. If a change occurs in the laser system configuration or operational parameters, evaluate the impact of this on the risk level
j. Establish a safety envelope of credited controls, including documentation, that are required to achieve acceptable risk and are subject to configuration control

3. Control Measures

3.1. General Considerations

Control measures:

a. *shall* prevent human exposure to hazardous laser radiation that exceeds the Class 3R limit, and
b. *should* mitigate visual interference effects from exposures below the Class 3R limit that can be a startle hazard

When selecting a laser to use or when operating a laser, the following requirements *should* be met:

a. Select the least hazardous laser (consider the Class, power and accessible wavelengths) that meets the operational requirements.
b. Operate the laser with the minimum amount of laser radiation needed.

To determine control measure requirements, the following steps *shall* be followed:

a. Determine the class of the laser or laser system.
b. Fulfill the requirements specified for that class of laser or laser system.
c. Perform a hazard evaluation or risk assessment (see Section 2) appropriate to the application. Determine if any requirements should be added or removed, while ensuring that the mitigated risk is acceptable.

3.2. Hazard Control Hierarchy

Once a hazard is identified, a hazard control hierarchy *shall* be applied to determine how to mitigate the hazard. One *should* first try to eliminate the hazard or make a substitution to reduce the hazard level. When elimination and substitution are not practical, then a selection of engineering, administrative, and PPE controls *shall* be implemented to reduce risk to an acceptable level. Engineering controls are prioritized over administrative and PPE controls because they are the most reliable. Where practical, they can be used to minimize the laser hazard by fully enclosing the laser beam. To ensure engineering controls are effective, they must have good integrity, be reliable, and be implemented in accordance with good engineering practices. When engineering controls cannot fully mitigate the laser hazards, then additional administrative and PPE controls *shall* be employed. The prioritization for controls implementation is illustrated in Figure 3-1.

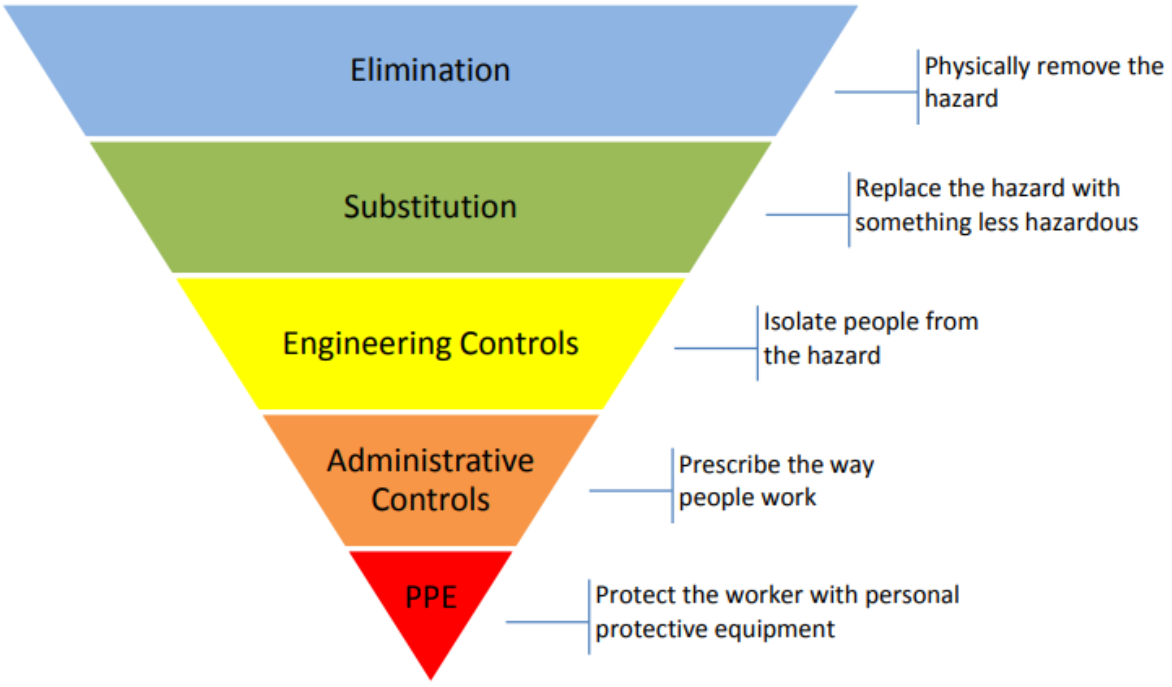

Figure 3-1: Hazard Control Hierarchy

3.3. Alternate Controls

Alternate controls may be used to replace control requirement(s) in this document, provided all of the following requirements are met:

a. Alternate controls *shall* provide equivalent protection as would be accomplished with the specific control(s) not used
b. Alternate controls *shall* be reviewed and approved by the LSO
c. Alternate controls training *shall* be provided to all affected laser workers

Informational Notes:

i. Alternate controls may be needed when the primary controls specified in this document are not feasible or not reasonably practicable.
ii. Examples of situations where an alternate control may be needed include:
  a. acceptance testing of a newly received laser
  b. service work by a service subcontractor
  c. <20 mW cw visible laser operation
iii. Examples of alternate controls may include one or more of the following:
  a. no unattended operation
  b. a guard be posted
  c. if an enclosure is not interlocked, then it is secured and has a warning label
  d. simple beam paths and perimeter barriers, and no out-of-plane beams

3.4. Engineering Controls

3.4.1. LCA Warning Device

An LCA Warning Device *shall:*

a. be installed at the LCA entryway so it is visible prior to entry
b. be installed inside the LCA

An LCA Warning Device *should:*

a. be easily viewable to persons in the LCA
b. be electronically interfaced to a laser power supply, safety shutter, or SIS

An exception to the LCA Warning Device requirements above is permitted in cases where the Laser Safety Officer (LSO) determines that the NHZ within the LCA is very limited in extent. In this case the LSO *shall* require an NHZ warning device, sign or label to clearly communicate where laser radiation may be present above Class 3R levels.

3.4.2. Emergency Stop Device

A Class 4 LCA *shall*:

a. have a clearly marked Emergency Stop (OFF) device

A Class 3B LCA *should:*

a. have a clearly marked Emergency Stop (OFF) device

3.4.3. Remote Interlock Connector

Each Class 3B and Class 4 laser source *should*

a. have a remote interlock connector

3.4.4. Master Key

A Master Key *shall:*

a. be provided for all Class 3B and Class 4 lasers or laser systems

Informational Notes:

i. A single Master Key can be used for multiple lasers. An LCA may have a single Master Key or multiple Master Keys.

ii. A common practice is for an LCA to have a SIS with an associated Master Key that disables all Class 3B and Class 4 lasers within the LCA when it is removed or turned to the OFF position.

3.4.5. Beam Stop/Attenuator

A beam stop or attenuator *should:*

a. be provided for each Class 3B and Class 4 laser or laser system

Informational Notes:

i. This can be used when the laser output is not required.

ii. This can be an insertable safety shutter interfaced with a SIS to disable a laser hazard when there is an interlock fault.

iii. This can be an intensity control for the source laser, for example by reducing the repetition rate or by reducing the excitation source.

3.4.6. Enclosures (Protective Housings, Class 1 Enclosures, Beam Conduits and Fiber Transport)

Informational Notes:

i. An enclosure that does not meet the requirements of a protective housing or a Class 1 enclosure is considered a barrier.

ii. Protective housings and Class 1 enclosures may incorporate beam conduits and fiber transport cables.

iii. A protective housing may or may not have an output aperture.

iv. An enclosure may be a Class 1 enclosure for some wavelengths but only a protective housing or a barrier for other wavelengths.

3.4.6.1. Removable Covers for Protective Housings, Class 1 Enclosures, and Beam Conduits if used as part of a Class 1 Enclosure

a. Covers that may be removed during normal operation or maintenance *shall* be provided with failsafe or redundant interlocks

b. Covers that are only removed during infrequent service tasks *shall* either:

- be interlocked (failsafe or redundant interlocks not required), or
- be secured requiring a tool to remove

c. If defeatable interlocks are used, it *shall* not be possible to replace the cover with the interlock defeated

d. If defeatable interlocks are used, the cover *shall* have a warning label to identify this

3.4.6.2. Removable Connectors for Fiber Transport Cables

a. Class 3B and Class 4 laser sources to the fiber transport cables *shall* be blocked or disabled prior to connecting or disconnecting the fiber

b. Removable connectors *shall* 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

3.4.6.3. LCA in *Exclusion* mode, Walk-in Protective Housings

a. These *shall* have fail-safe or redundant access control interlocks to disable laser hazards in excess of Class 3R if a person enters

b. An LCA Warning Device *shall* be used which indicates a *NO ACCESS* condition

3.4.6.4. Equipment Labels

3.4.6.4.1. Protective Housings

An equipment label providing hazard information for the output laser beam *shall:*

a. be affixed to a conspicuous place on the housing

b. be placed on the control panel if it is separated from the housing by more than 2 meters

3.4.6.4.2. 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 *shall:*

a. be affixed to each removable cover
b. include the following text (or equivalent)

- if no interlocks for cover, "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"

3.4.6.4.3. Removable Fiber Connectors

A warning label identifying the highest class of laser radiation contained within the fiber *shall:*

a. be affixed to each removable fiber connector
b. include the warning statement (or equivalent) "Hazardous Laser Radiation may be Accessible when Disconnected"

3.5. Administrative and Procedural Controls

3.5.1. Standard Operating Procedures (SOPs)

SOPs for Class 3B and Class 4 lasers *shall*:

a. be required and approved by an LSO
b. include alignment procedures

SOPs for Class 3B and Class 4 lasers *should* include the following items -- if not included in the SOP, they *shall* be documented elsewhere:

a. laser hazard parameters (power, pulse energy, pulse width, repetition rate)
b. OD requirements and required PPE
c. engineering and administrative controls
d. schematic of the LCA including where the lasers, emergency stop buttons, and external safety shutters are located

Informational Note: Examples of alternative documentation could be:

i. local posting of the LCA schematic
ii. local posting of OD and PPE requirements at entry to LCA

3.5.2. Alignment Procedures

Each of the following actions *shall* be addressed in an SOP document:

a. an alignment action that changes the wavelength hazard or eyewear requirement

Each of the following actions *shall* be addressed in training, an SOP document or by another method:

a. Laser eyewear protection is required for accessible Class 3B and Class 4 beams
b. Have good viewing diagnostics readily available (for example: fluorescent cards, cameras, UV/IR viewers)
c. Block beams when not needed
d. Use barriers or irises to prevent or block stray beams. Check for stray beams at each step in the alignment procedure (e.g., before moving on to the next optical component) and prior to high power beam operation
e. Perform safety inspection for proper beam containment and ensure all safeguards are in place when completing the alignment task
f. Peeking over or under laser eyewear is not allowed
g. Avoid bringing eyes near plane in which laser propagates

Each of the following actions *should* be addressed in training, an SOP document or by another method:

a. Exclude unnecessary personnel
b. When practical use low power alignment lasers
c. Attenuate high power laser beams to the lowest practical power

d. Place beam blocks or barriers behind optics (e.g., turning mirrors) to terminate beams that might miss mirrors during alignment
   Informational Note: More attention is needed for implementing local beam blocks and barriers when optics are used outside a region that has associated perimeter barriers.
e. Terminate beams down range of optics being aligned. Ensure proper beam termination prior to high power operation
f. Ensure appropriate warning signs or displays are used for alignment or maintenance tasks
g. Reduce unwanted reflections by using non-reflective tools and non-laminated viewing cards
h. Practice good housekeeping to remove unnecessary tools, components and combustibles
i. Document training for laser workers who perform alignment tasks

3.5.3. Unsupervised, Unattended Operation

3.5.3.1. Unsupervised laser operation

a. Unsupervised laser operation *shall* not be permitted

Informational Note: some manufactured Class 1 laser systems do not require supervised operations. For example, laser printers and CD players do not require supervised operations. However, a manufactured laser welder would require supervised laser operation.

3.5.3.2. 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 *shall* be permitted only when all of the following are satisfied:

a. the Laser Supervisor has ensured that control measures, consistent with the controls hierarchy, provide adequate protection to those who may enter the laser controlled area during times of unattended use
   Informational Note: these controls may include interlocks, beam traps, barriers, other means of area control, or laser safety training.
b. the laser supervisor has ensured that appropriate engineering controls restrict access to the LCA to authorized laser workers
c. for Class 4 LCAs, the entryway to the LCA is interlocked to disable accessible Class 3B and Class 4 laser beams if there is an unauthorized entry to the LCA

The unattended use of Class 3B or Class 4 lasers or laser systems *should* require each of the following:

a. the entryway to the LCA be locked, with access restricted to authorized laser workers
b. for Class 3B LCAs, the entryway to the LCA be interlocked to disable accessible Class 3B laser beams if there is an unauthorized entry to the LCA

3.5.4. Configuration Control

A configuration control process *should* be followed for any work that modifies the safety envelope, unless the work and safety controls for it are adequately described in the approved laser safety documentation (e.g., SOP).

Examples of work activities that may require configuration control are:

a. modifying a Class 1 enclosure, a safety shutter configuration, or a component of the engineered SIS
b. changing an attenuator, if this changes the laser classification and hazard controls
c. work that results in a configuration that is outside the scope of the approved laser safety documentation.

A laser safety configuration control form may be used for this process. When this is done, the form *should* include the following information:

a. scope of work to be performed and its purpose
b. safety requirements to be completed before the work starts
c. safety requirements while the work is being done and laser system is in a modified state
d. safety requirements to restore normal operations
e. names and dates for persons performing the work and safety checks, together with their signatures.

3.5.5. Annual Inspections/Audits

Annual inspections of laser facilities (or laser systems) by the LSO or Deputy LSO *shall* include, at a minimum, all of the following:

a. review that the current SOP(s), and other laser safety documentation if applicable (e.g., laser inventory, laser hazard parameters and associated hazard analysis for laser eyewear OD calculations), accurately reflects current laser operations and is readily available
b. verify that laser system interlock functionality checks have been completed
c. review list of authorized laser workers and verify that their training is current, including any required OJT
d. review lasers in use and that their operations are adequately described in the SOP document(s)
e. review that LCA entryway postings meet requirements and use the correct signal word (CAUTION, WARNING or DANGER)
f. inspect eyewear and eyewear storage location that requirements met, including that the eyewear is not damaged, only approved laser eyewear is present and eyewear information is clearly legible
g. check if barriers and beam containment are adequate
h. check if optics are adequately secured
i. check if housekeeping is adequate
j. review status of open action items from last inspection

3.6. Personal Protective Equipment (PPE)

3.6.1. Full Protection Laser Eyewear

Full protection laser eyewear *shall*:

a. be required whenever Class 3B or Class 4 laser radiation is accessible within the NHZ, unless the LSO approves use of alignment eyewear
b. be required for all routine laser operations and for most laser alignment procedures

3.6.2. Alignment Eyewear

Alignment eyewear *shall*:

a. only be used for specific visible wavelength alignment procedures that have been appropriately evaluated, documented, and authorized by the LSO
b. have a minimum OD requirement that provides full protection for viewing at 20 cm distance an ideal, point-source, diffuse reflection of the laser source.

Laser workers who use alignment eyewear *shall*:

a. be notified that alignment eyewear will not protect them against a point source intrabeam exposure

3.6.3. Skin PPE

Skin PPE *shall* be used:

a. if there may be UV radiation exposure above the MPE

Informational Notes: Consideration needs to be given for:

i. chronic exposures to diffuse laser radiation hazards
ii. use of a full-face shield in addition to gloves and long-sleeved clothing for high-powered laser operations

3.7. Signs and Labels

LCA Warning Signs and laser equipment labels *shall* comply with requirements in ANSI Z136.1. Also refer to 3.4.6.4 in this document for equipment label requirements for protective housings, Class 1 enclosures and fiber optics connectors.

3.8. Special Topics

3.8.1. Controls for High Power Lasers, High Pulse Energy Lasers, and Laser Systems with an Ionizing Radiation Hazard

For the controls requirements in this section, we consider:

a. *High Power Laser - A laser that emits ≥10 kW average power in a period ≥ 0.25 seconds.*
b. *High Pulse Energy Laser - A laser that emits ≥100 J laser energy in a period ≤0.25 seconds.*
c. *Laser System with an Ionizing Radiation Hazard - A laser system for which the hazard evaluation identifies this exists (see 2.1.2)*

These lasers are considered immediately dangerous to a worker's health. The concern becomes skin and whole-body exposure, rather than just eye exposure.

Engineering Controls

a. For High Power Lasers, the walls of the LCA *shall* be engineered to prevent a misdirected laser beam from penetrating to an uncontrolled area if the risk assessment determines this is required. This may require materials beyond typical building wood/drywall construction if the irradiance could exceed ~5 kW/cm^2.
b. For laser systems with an ionizing radiation hazard, radiation shielding *shall* be implemented if the risk assessment determines this is required.
c. For High Power and High Pulse Energy Lasers, to prevent laser beams from leaving the laser table in the event of an optic component failure, beam dumps/barriers of substantial material or with appropriate water cooling *should*:
    - be used behind turning mirrors
    - be able to withstand failure long enough for a safe shutdown
    - be permanently mounted onto the optical table
d. an evaluation *shall* be done to determine if an *Exclusion* operation mode is required for the LCA.
e. an *Exclusion* operation mode for the LCA *should* be implemented for High Power Lasers above 100 kW
f. When an *Exclusion* mode is employed,
    - requirements in 3.4.6.3 for *Exclusion* mode *shall* be met
    - Cameras *should* be used to observe the laser operation in the case of an incident, so that operators may shut down the system
    - a remote operating/control station *should* be employed
    - engineered search controls *shall* be used as part of the safety interlock system to ensure personnel are removed from the LCA prior to laser operations in this mode. Search controls may include one or more of the following: a search key, search buttons or key locks, and RFID authorization.

      Informational Notes: As an example, the following Search Key control may be used:
        i. *Key is removed from the control panel and used to lock out the LCA at various stations and access points.*
        ii. *Key is returned to the operator's console in order to operate the laser in Exclusion mode.*
g. A PLC-based SIS *should* be used. If a PLC is used and an *Exclusion* mode is employed, the PLC *should* be a safety PLC. Compared to a regular PLC, safety PLCs have extra features such as:
    - redundancy
    - hardware functionality adheres to a specific Safety Integrity Level (SIL)
    - locked logic or safety signatures to ensure that coding has not been changed
    - ability to perform field device checking such as monitoring for broken wires, failed contacts, etc.
h. Where the output laser beam (pulsed or continuous wave) may "drill" through a shutter/beam stop, layered controls *should* be used to ensure there is no single point of failure. This may be in the form of multiple in-line shutters, thermal sensors, etc.
i. Additional engineering controls *shall* be implemented if the risk assessment determines they are required. These may include:
    - temperature sensors and/or flow sensors on water-cooled optics or beam dumps
    - smoke detectors

- beam loss monitors
- burn-through monitors

Administrative Controls

a. A documented Risk Assessment (see Section 2.1) *shall* be completed to ensure implementation of safety for the system is understood. As part of the Risk Assessment, a documented Failure Modes and Effect Analysis (FMEA) *should* be performed. For laser systems with an ionizing radiation hazard, a radiation safety subject matter expert shall be contacted to conduct the risk assessment.
b. The following *shall* be documented, reviewed and approved:
   - SIS specification
   - SIS logic (e.g., ladder logic for PLC code)
   - SIS certification procedures
c. Configuration management of all components and documentation serving as credited controls for the safety envelope *shall* be employed to ensure an "as-built" system is maintained.
   - When a component is replaced, it *shall* be documented and approved by the LSO.
   - Configuration control requirements described in Section 3.5.4 *shall* be implemented

   Credited controls generally include the SIS, the laser system SOP document(s), laser worker training (including OJT) and laser eyewear PPE.

PPE

a. The use of laser protective "goggles" rather than spectacles *should* be considered in cases where there is a considerable diffuse reflection nominal hazard zone or where visible diffuse reflections can be a distraction hazard.
b. Where the MPE for eye exposure is exceeded by $\geq 10^7$, remote operation *should* be considered over the use of laser eyewear.

3.8.2. Controls for Class 1 Lasers with embedded Class 3B, Class 4 Lasers

A Class 1 laser system or a laser system configured for Class 1 operation is not a laser exposure hazard and requires no PPE control measures.

Control measures for Class 1 laser systems include:

a. Engineering Controls
   - The laser system enclosure *shall* fully enclose the laser beam and any reflections during normal operation, such that no light can escape the enclosure at levels above the Maximum Permissible Exposure (MPE).
   - Laser enclosure barrier materials *should* be rated or tested to withstand continuous direct and diffusely scattered beams without material failure.
   - Viewports/viewing windows, if used as part of the laser system enclosure, *shall* be constructed of materials with the appropriate optical density (OD) and damage threshold rating.
   - Enclosure access panels *shall* meet the requirements in 3.4.6.1.
   - A visual indicator *should* be implemented that is visible outside of the enclosure and indicates to the operator whether the laser is operating.
   - The laser *shall* be operated and controlled from outside its enclosure.

b. Administrative Controls
   - Enclosure *shall* meet the labeling requirements in 3.4.6.4.2.
   - If the system is not operated in a Laser Control Area (LCA) and engineering controls are not implemented to notify personnel of the laser operation, signage *shall* be posted to notify personnel that a Class 1 laser with an embedded Class 3B or Class 4 laser is being operated.
   - The LSO *shall* review and approve all user-built Class 1 enclosures
   - The LSO *shall* review and approve all commercial Class 1 enclosures if they have a cover or access panel that can be removed or opened by the laser user which allows access to the enclosed Class 3B or Class 4 laser.

     Informational Note: some commercial Class 1 laser products have interlocked access panels which allow the user to bypass or defeat the interlock.
   - Equipment-specific training *shall* be required for workers who operate, maintain or service Class 1 lasers with an embedded Class 3B or Class 4 laser, if they have a cover or access panel that can be removed or

opened by the laser user which allows access to the enclosed Class 3B or Class 4 laser. Laser workers *shall* receive training for tasks when beam access is required during maintenance and/or service.

- Equipment-specific training *shall* be required for workers who operate, maintain or service user-built Class 1 lasers with an embedded Class 3B or Class 4 laser.

3.8.3. Laser Transport between Two LCAs

When a Class 3B or Class 4 laser beam can be transported between two LCAs or could be transported from an LCA to an uncontrolled area, then the following control requirements are applicable:

a. Two engineered controls *should* be implemented that can prevent the beam transport, so there is not a single point of failure
b. The SIS for the LCA that receives the transported beam *should* include:
    i. Status for the device(s) used to prevent beam transport (e.g., *Closed* position sensor for a safety shutter or valve)
    ii. An illuminated display sign to communicate the laser hazard status in the LCA (e.g., LASER OFF, LASER IMMINENT, LASER ON). One sign *should* be located at the entry to the LCA so it can be viewed prior to entry, and one sign *should* be located within the LCA so it can be viewed by workers within the LCA.
c. Device(s) used to prevent beam transport *should* be controlled locally within the LCA that receives the beam when workers can be present there
d. A Risk Assessment (see Section 2.1) *should* be completed to ensure implementation of safety for the system is understood.
e. Laser workers *shall* receive specific training on the laser transport and controls. This training *should* be documented.

3.8.4. Laser Manufacturer Requirements and FDA Compliance

The Food and Drug Administration (FDA) has regulatory requirements for laser products, which are described in 21CFR 1040.10 and 21CFR 1040.11. Certification requirements for electronic products, including laser products, are described in 21CFR 1010.2.

Laser products purchased by DOE facilities *shall*:

a. meet FDA requirements in 21 CFR1040.10, 21 CFR1040.11 and 21 CFR1010.2, except as described in FDA Laser Notice 25 and FDA Laser Notice 56

Informational Note: Laser components are exempt from FDA requirements (see 21 CFR 1040.10)

3.8.4.1. Non-certified Commercial Lasers and Laser Notice 25 Compliance

DOE facilities that use non-certified laser products as described in Laser Notice 25,

a. *Shall* report to FDA/CDRH an inventory of said laser(s) on an annual basis.
b. This inventory and report *shall* be completed in the first quarter of each fiscal year with report being submitted no later than last day of the quarter.
c. Official reporting to FDA *shall* be required to be completed beginning FY24.
d. Each non-certified laser *shall* be identified on a standard individual report form.
e. The LSO for each reporting location *shall* maintain an updated inventory of said lasers for review. Locations that do not have these non-certified lasers are not required to report to FDA.

3.8.4.2. Commercial Lasers Certified per IEC Safety Standards and Laser Notice 56 Compliance

Laser products that utilize Laser Notice 56 (and are not considered a medical device) are required to have a certification label stating:

a. "Complies with FDA performance standards for laser products except for conformance with IEC 60825-1 Ed. 3., as described in Laser Notice No. 56, dated May 8, 2019." or
b. "Complies with 21 CFR 1040.10 and 1040.11 except for conformance with IEC 60825-1Ed. 3, as described in Laser Notice No. 56, dated May 8, 2019."

3.8.4.3. DOE-built Lasers, Modified Commercial Lasers and FDA Laser Notice 14

As part of scientific work, DOE facilities sometimes build laser products from laser components, or they may modify a commercial laser product. Examples include:

a. adding optical components to a commercial laser that change the wavelength or other laser parameters
b. incorporating a commercial laser into a larger laser system

Such lasers are generally used solely at the DOE site where they were built, but at times one DOE location may build a laser system for another DOE site.

Laser Notice 14 describes that such DOE-built or DOE-modified laser products are exempt from FDA manufacturer requirements if they are for the sole use by the DOE, unless they are made on a continuing basis in the course of a commercial enterprise and are used by employees other than those directly involved in their manufacture.

A DOE site *shall* meet FDA requirements for laser manufacturers if:

a. they build a laser product from components or modify a commercial laser product, and then provide this laser or laser system to a non-DOE site

4. Training

4.1. Laser Safety Officer (LSO) Training

LSO training *shall*

a. be provided by management
b. be commensurate to the highest Class of laser under the jurisdiction of the LSO
c. include potential hazards, control measures, medical examinations, applicable standards, and non-beam hazards

LSO training *should*

a. include obtaining LSO certification by the Board of Laser Safety

Informational Note: Minimal training for an LSO is typically a commercially available 5-day Laser Safety Officer Training course WITH Hazard Analysis.

4.2. Laser Supervisor Training

Laser supervisors *shall:*

a. complete the National Training Center ESH-518 DOE Laser Worker Training or equivalent

Laser supervisors *should* complete each of the following:

a. training required of laser workers for lasers that are under their authority
b. laser beam alignment training
c. training commensurate with their supervision responsibilities

4.3. Laser Worker Training

Workers *shall* complete all of the following:

a. the National Training Center ESH-518 DOE *Laser Worker Training* or equivalent
b. *On-the-Job Training* (*OJT*) for the laser systems and laser facilities they are authorized for
c. hands-on training or demonstrate proficiency for specific lasers and laser systems the workers use
d. laser beam alignment training or demonstrate proficiency in this, if they perform alignment tasks.
e. additional training for non-beam hazards if applicable

Informational Note: this is particularly important for electrical and fire hazards.

Workers *should*:

a. have their OJT, hands-on training and alignment training (or demonstrated proficiencies in these) documented as applicable

5. Medical Exams

5.1. Skin Exams (UV)

Laser Workers *should*:

a. request a skin exam if they experience any symptoms from exposure to UV laser beams
b. request a periodic skin exam if they are working with UV lasers and are at risk for exposure above the MPE, in particular if they have a history of photosensitivity

5.2. Exams Following a Suspected or Actual Laser-Induced Injury

Medical examinations *shall* be performed as soon as practical, preferably within 48 hours, when a suspected injury or adverse biological effect from a laser exposure occurs.

6. Laser Safety Programs

6.1. Laser Safety Officer Responsibilities

LSOs *shall*:

a. participate as a member of the DOE EFCOG Laser Safety Task Group (LSTG)

6.2. Laser Supervisors

6.2.1. Assignment and Authority

Laser supervisors *shall*:

a. be assigned by their line management for a laser system, LCA or laser project; and
b. have the authority granted by management to carry out the responsibilities of their job

6.2.2. Roles and Responsibilities

Laser supervisors *shall* fulfill all of the following requirements:

a. be knowledgeable of the institutional laser safety policies and requirements
b. understand the laser safety hazards and controls, including the SOPs, for the lasers under their authority
c. only permit operation of Class 3B and Class 4 lasers with approval of LSO
d. ensure SOPs and appropriate training, including OJT, are provided to laser workers on all laser hazards and their controls,
e. ensure adequate work planning and control for safe laser operations
f. ensure that proper controls are in place
g. provide the LSO with the names of all laser workers
h. suspend laser operation if there is inadequate control of laser hazards
i. respond promptly and appropriately to all laser incidents or accidents, including to notify the LSO
j. assist in obtaining appropriate medical response if needed, for all laser incidents or accidents
k. notify the LSO of any new installations or modifications to laser systems that may deviate from the hazards and controls already approved

Laser supervisors *should* fulfill all of the following requirements:

a. document OJT for laser workers, even if not formally required at their DOE site

6.3. Laser Workers

6.3.1. Authorization

Laser Worker authorization *shall:*

a. require approval from their administrative supervisor and the laser supervisor; and
b. be documented

6.3.2. Roles and Responsibilities

Laser Workers *shall* fulfill all of the following requirements:

a. not operate a laser unless authorized to do so
b. comply with all safety rules and procedures applicable to the laser system and the laser facility for which they are authorized
c. immediately report all laser accidents/injuries or any incident that could have led to an injury to their supervisor, and if not available to the LSO

6.4. Approval Requirements (SOPs, Laser or LCA Operations, Laser Workers)

Informational Notes:

i. Different DOE sites have different terminology for SOP documents, or they may be incorporated into another document. Examples include: Work Control Document and Integrated Work Document.

ii. Some DOE sites may use a "review and concur" requirement for the LSO, Deputy LSO, safety representative, manager or supervisor instead of "approve" for the requirements noted in this section.

6.4.1. SOP Documents

SOP documents *shall* meet all of the following requirements:

a. be approved by the LSO or Deputy LSO
b. be approved by a safety representative, whose responsibilities include reviewing non-beam hazards
c. be approved by a manager or supervisor responsible for the laser(s) described in the SOP or for the laser facility where they will be operated

6.4.2. Laser or LCA Operations

Laser or LCA operations *shall* meet all of the following requirements:

a. be approved by the LSO or Deputy LSO
b. be approved by a safety *representative*, whose responsibilities include reviewing non-beam hazards
c. be approved by a manager or supervisor responsible for the laser(s) described in the SOP or for the laser facility where they will be operated
d. be approved for a specified time period

6.4.3. Laser Workers

Laser workers *shall* meet all of the following requirements:

a. be approved or authorized by a laser supervisor responsible for each applicable laser, laser system or LCA
b. be approved by their administrative supervisor for each applicable laser, laser system or LCA
c. have completed the required training at their DOE site for laser workers

References

1. LSCP Report, *Guidance on Laser Safety Requirements for Control Measures, Training and Laser Safety Programs* R000, August 5, 2019. Available from the website for the DOE EFCOG's laser safety group, https://efcog.org/safety-working-group/worker-safety-health-subgroup/laser-safety-task-group/.
2. ANSI Z136.1-2014, *American National Standard for Safe Use of Lasers*
3. ANSI Z136.8-2021, *American National Standard for Safe Use of Lasers in Research, Development, or Testing*
4. ANSI Z136.9-2013, *American National Standard for Safe Use of Lasers in Manufacturing Environments*
5. References that describe ionizing radiation hazards when laser intensities exceed 10^{15} W/cm^2 include:
    a. T. Liang, et al. (2017) Bremsstrahlung Dose Yield for High-Intensity Short-Pulsed Laser-Solid Experiments, *Radiat. Prot. Dosim*. **175**, 304.
    b. T. Liang (2017) Characterization of Ionizing Radiation Generated from Interaction of High-Intensity Laser with Matter, Ph.D. Thesis, Georgia Institute of Technology.
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    e. S. Vallieres, J. Powell, et al. (2022) High Dose-Rate Ionizing Radiation Source from Tight Focusing in Air of a mJ-class Femtosecond Laser, 2207.05773.pdf (arxiv.org).
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    a. H. Legall, et al. (2018) X-ray Emission as a Potential Hazard during Ultrashort Pulse Laser Material Processing, *Appl. Phys. A* **124,** 407.
    b. H. Legall, et al. (2020) X-ray Radiation Protection Aspects During Ultrashort Laser Processing, *J. Laser Appl.* **32,** 022004.
    c. M, Wesolowski, et al. (2017) X-Ray Dosimetry during Low-Intensity Femtosecond Laser Ablation of Molybdenum in Ambient Conditions, *IEEE Trans. Nucl. Sci.*, **64**, 2519.
    d. R. Behrens, B. Pullner, M. Reginatto (2019) X-ray Emission from Materials Processing Lasers, *Radiat. Prot. Dosim*. **126**, 361.
    e. R. Weber, et al. (2019) Expected X-ray Dose Rates Resulting from Industrial Ultrafast Laser Applications, *Appl. Phys. A* **125,** 635.
7. *Performance Standard for Laser Products* 21CFR1040.10
8. *Performance Standard for Specific Purpose Laser Products* 21CFR1040.11
9. *Certification Requirements for Electronic Products*, 21CFR1010.2
10. FDA Laser Notice 25, September 1979
11. FDA Laser Notice 56, May 2019
12. FDA Laser Notice 14, November 1976

Appendix

A.1. Example Laser Hazard Parameters Table

Table A-11: Maximum operating laser hazard parameters and laser eyewear OD requirement

Laser system	λ (nm)	Average Power	Pulse width (FWHM)	Pulse Energy	Repetition rate	Minimum OD
Regen pump laser	527	45 W	250 ns	45 mJ	1kHz	5.8
Oscillator pump laser	532	5.0 W	cw	--	--	3.7
Oscillator	800	600 mW	10 fs	8.9 nJ	80MHz	3.0
Regen, before compressor	800	12 W	100 ps	12 mJ	1 kHz	5.0
Regen, after compressor	800	7.5 W	25 fs	7.5mJ	1kHz	5.9
Regen 2nd Harmonic	400	500 mW	25 fs	0.5 mJ	1kHz	4.7

A.2. Example FMEA

Table A-2: Failure Mode and Effects Analysis Summary
(see Appendix A.3 for descriptions of probability, consequence and risk)

Failure Item	Potential Failure Mode	Potential Failure Effect	Potential Causes	Consequence Before Mitigation	Probability Before Mitigation	Mitigation	Risk After Mitigation
500-kW laser beam	Laser burns through wall	Personnel exposure outside of LCA	Misaligned laser beam	High	Low	Gypsum wall material, cameras on beam path	Extremely Low
	Personnel exposure	Laser burn	Personnel enter beam path	Medium	Low	Remove personnel from LCA	Extremely Low
Laser optics	Shrapnel from failing parts	Personnel injury	High irradiance beam	Medium	Medium	Remove personnel from LCA	Extremely Low
Laser	Loss of cooling water	Laser overheating damages laser	Cooling pump failure	Medium	Medium	Thermal sensors to shut down laser	Low

A.3. Example Risk Matrix

Table A-3: Risk Matrix

Consequence \ Probability	Extremely Low	Low	Medium	High
High				
Medium				
Low				
Extremely low				

Risk Level		
	High	Unacceptable
	Medium	Unacceptable
	Low	Acceptable
	Extremely low	Acceptable

Table A-4: Probability and Consequence Descriptions for a Risk Assessment

Category	Probability	Consequence
High	Occurrence is likely to occur several times per year	Serious impact on-site or off-site. May cause deaths or loss of the facility/operation. Significant regulatory or contractual violation.
Medium	Occurrence is likely to occur annually	Major impact on-site or off-site. May cause severe injuries or severe occupational illness to personnel or major damage to a facility. Capable of returning to operation. May result in regulatory or contractual violation.
Low	Occurrence is likely to occur during the life of the facility or operation	Minor on-site with negligible off-site impact. May cause minor injury or minor occupational illness. De minimus regulatory or contractual violation.
Extremely Low	Occurrence is unlikely or the event is not expected to occur during the life of the facility or operation	Will not result in a significant injury or occupation illness.