FESHM 4260: LASERS

Revision History

Author	Description of Change	Revision Date
Matthew Quinn	• Reference ANSI Z136.1-2014. • Changed Class terminology to align with Z136.1-2014. • Added LCA Keyholder and responsibilities.	January 2019
Matthew Quinn	Revised to conform to updated FESHM template.	August 2015
Matthew Quinn	• Added a section (3.4) on employee responsibilities. • Added section 5.0 on laser registration. • Changed labeling of subsequent sections for consistency. • Made several minor edits for chapter organization and clarity.	March 2013
Matthew Quinn	Added a technical appendix on laser pointers, laser sign / label artwork, and a reference to the FDA laser standard. Chapter reformatted to fit the standard layout scheme.	5 Year Review September 2011

TABLE OF CONTENTS

1.0 INTRODUCTION

The purpose of this program is to mitigate the hazards posed by lasers and laser systems that operate at wavelengths between 180 nm and 1000 µm. The hazards from high-power Class 3B or 4 lasers used at Fermilab and Fermilab leased spaces can include eye damage, skin burns, electric shock, fire, explosion, air contaminants, and production of ionizing radiation. Lower power Class 2 and 3R lasers are safe when used as intended but may require some controls. Hazard control measures are determined by the class of laser to be used.

This document details responsibilities and requirements for the safe use of lasers in accordance with ANSI Z136.1-2014. The program applies to the acquisition, approval, and operation of all lasers at Fermilab and all Fermilab leased spaces by Fermilab employees, visitors, and subcontractors.

2.0 DEFINITIONS

Diffuse viewing - Refers to looking at scattered radiation such as occurs during many alignment activities.

Failsafe interlock – An interlock where the failure of a single interlock component will cause the system to go into, or remain in, a safe mode.

Interlocked – With regard to a laser radiation enclosure, "interlocked" means that laser radiation levels are automatically reduced to harmless levels when a protective enclosure is opened. If the interlock is not failsafe, an appropriate warning label must also be attached to the enclosure.

Intrabeam viewing - Refers to direct or specularly-reflected eye exposure as might occur in an accident.

Laser Controlled Area (LCA) – A laser use area where the occupancy and activity of those within is controlled and supervised. This area may be defined by walls, barriers, or other means. Within this area, potentially hazardous beam exposure is possible.

LCA Keyholder – A worker who possesses a key to a LCA, but who is not authorized to work with Class 3B or 4 lasers. These personnel typically hold LCA keys for administrative or emergency purposes. Fermilab laser safety training is required for these workers so that they understand the hazards that may be present in the LCA. The laser eye exam is still required even though they are not authorized to work with lasers.

Laser Safety Committee – A group that meets regularly to review laser safety activities at Fermilab and leased spaces. Membership includes the laser safety officer, deputy laser safety officer, laser safety representatives, and Division Safety officers where laser activities presenting significant risk are taking place. This mainly involves activities with hazard Class 4 lasers.

Laser Safety Officer (LSO) – Individual who has authority and responsibility to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards.

Laser Supervisor – The supervisor of individuals working with or having the potential for exposure to laser radiation. They can represent a laser's operation with regard to its ES&H aspects. This is typically the person responsible for day-to-day management of the laser system.

Locked – With regard to a laser radiation enclosure, "locked" means that a tool is required to gain access to the laser beam and an appropriate warning label has been attached to the enclosure.

Maximum Permissible Exposure (MPE) – The level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. The MPE is a complex function of wavelength, modulation and exposure duration.

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

Public – For the purposes of laser safety, individuals whose access to laser radiation is not explicitly controlled by the laser operator. For public displays, there must be a lateral distance of at least 2.5 m between hazardous levels of laser radiation and locations where members of the public are permitted. The minimum vertical distance between hazardous levels of laser radiation and surfaces upon which members of the public may stand is 6.0 m. The vertical distance can be reduced to 3.0 m if the laser system is continuously controlled by an experienced trained operator who maintains constant surveillance of the laser display and can terminate the laser emission in the event of a problem.

Spectator – For the purposes of laser safety, an individual whose access to laser radiation is explicitly controlled by the laser operator.

Tool - With regard to a laser radiation enclosure, the requirement for a "tool," when used in conjunction with a warning label, greatly reduces the likelihood of inadvertent access to hazardous laser radiation levels. A key to a lock is considered a tool for the purposes of this chapter.

3.0 RESPONSIBILITIES

3.1 Laser Safety Officer (LSO) or Deputy LSO

The LSO plays a Lab-wide oversight role in the evaluation and control of laser hazards including system classification, procedures, protective equipment, warning systems, facilities, training, and medical surveillance. When the LSO is unable to fulfill these responsibilities, these duties fall to the Deputy LSO.

- Reports to the Chief Safety Officer to inform them of laser projects at the lab and/or leased spaces and advise them on laser safety policies and requirements.
- Establishes and maintains adequate policies and procedures for the control of laser hazards. These policies and procedures shall comply with applicable requirements including federal, state, and local regulations.
- Approves
  - Operation of all Class 3B and 4 lasers.
  - Standard operating procedures for all Class 3B and 4 lasers.
  - Control measures for lasers and laser systems.

- All Class 3B and 4 laser facilities and installations.
- Personal Protective Equipment to be used with Class 3b and 4 lasers.

- Classifies or verifies classification of lasers and laser systems.
- Conducts a hazard evaluation of laser work areas.
- Reviews wording on laser area signs and warning labels.
- Assures that adequate safety education and training are provided to laser personnel.
- Performs a periodic review of each Class 3B and 4 laser to check the functionality of control measures, and compliance with the lab's safety requirements.
- Provides laser users with guidance during and following an unlikely event of exposure, e.g., sensation in the eye, flash, etc.

3.2 Laser Safety Committee

The Laser Safety Committee plays a role in communication, consultation, and oversight for laser hazards associated with planned and active laser operations. It also provides a venue for participants to share expertise and equipment. Meeting frequency is adjusted to accommodate the pace of Class 3B and 4 laser activities, typically quarterly to monthly. Committee members include the LSO, Deputy LSO, laser supervisors and several key laser users.

3.3 Laser Supervisor

The supervisor of individuals working with or having the potential for exposure to laser radiation. An individual who represents a laser operation with regard to its ES&H aspects. This is typically the person responsible for day-to-day management of the laser system or laser room. The laser supervisor will submit a laser registration form, prepare and submit for LSO approval a standard operating procedure or hazard analysis, and affix labels before permitting Class 3B or 4 laser operations. The laser supervisor will maintain a current inventory of all lasers within his or her responsibility. The inventory will include the classification, wavelength, power, manufacturer, model, serial number, and FNAL ID number. The laser supervisor will suspend the operation of a laser when there is inadequate control of laser hazards and holds laser operators accountable for meeting laser safety requirements.

3.4 LCA Keyholder

LCA Keyholders are responsible for possession of keys to Class 3B or 4 LCAs and for allowing access to LCAs in emergencies or when the laser owner/operator are not available. They are not allowed to enter or permit entry to LCAs when Class 3B or 4 lasers are in operation, or the LCA is interlocked.

3.5 Employees

Employees who plan on bringing a laser of Class 3B or 4 to Fermilab or a leased space must ensure that it is registered with the LSO. This includes newly purchased lasers, lasers transferred from other locations, and lasers owned by other institutions. The process of registration is outlined below in Section 5. Users must also follow standard operating procedures for the laser they are using.

4.0 PROCEDURES

Below is a summary of the laser safety requirements at Fermilab. Precautions for beam hazards are presented according to hazard class and are based on ANSI Z136.1-2014. Though general in nature, this information provides a solid basis for understanding the required actions. Exhaustive guidance is available in the applicable standard, some of which is presented in subsequent pages of this chapter.

4.1 Hazard Class 1

4.1.1. Description

Any laser that requires more than eight hours of direct eye exposure to produce an injury. Considered harmless. The maximum output of a Class 1 visible wavelength CW laser ranges from 40 to 400 μW, depending on wavelength.

4.1.2. Precautions

Usually none. However, problems may arise if the laser is modified in a way that may increase its output or there is an embedded laser that has a higher hazard class. If these are encountered, follow the precautions for the appropriate hazard class.

4.2 Hazard Class 2

4.2.1. Description

A laser that emits radiation in the visible portion of the spectrum and requires more than 0.25 seconds of direct eye exposure to produce a retinal lesion. Since the bright light emitted from such a device triggers a "blink reflex", and most people can blink within 0.15 seconds, an injury can only occur by forcibly staring into the beam. Considered low hazard. The body has a mechanism to protect itself and significant retinal damage requires prolonged staring. The maximum output of a Class 2 CW laser is 1 mW. The wavelength of the radiation must be within the visible portion of the spectrum (0.4 to 0.7 μm).

4.2.2. Precautions

Do not stare into the beam. Do not point the laser in the direction of other people or shiny objects. Precautions for public displays apply (see definitions). As with hazard Class 1 lasers, problems may arise if the laser is modified in a way that may increase its output or there is an embedded laser that has a higher hazard class. If these are encountered, follow the precautions for the appropriate hazard class.

4.3 Hazard Class 3R

4.3.1. Description

A laser that has 1 to 5 times the output of a Class 1 laser in the invisible portions of the spectrum (<0.4 μm or >0.7 μm), or 1 to 5 times the output of a Class 2 laser at visible wavelengths (0.4 to 0.7 μm). In addition, the applicable exposure limit must not be exceeded, e.g., due to large beam diameter. For example, a Class 3R visible wavelength CW laser can have an output of 1-5 mW, as long as the irradiance does not exceed 2.5 mW/cm^2. Considered a modest hazard. This class includes many construction lasers.

4.3.2. Precautions

Do not stare at the beam or view directly with optical instruments. Do not point the laser in the direction of other people or shiny objects. Precautions for public displays apply (see definitions). As with hazard Class 1 lasers, problems may arise if the laser is modified in a way that may increase its output or there is an embedded laser that has a higher hazard class. If these are encountered, follow the precautions for the appropriate hazard class.

4.4 Hazard Class 3B

4.4.1. Description

Any laser that exceeds hazard Class 3R, but less than Class 4. At visible and infrared wavelengths (>0.4 μm), a 3B laser can cause eye injury within the time it takes to blink. This applies to the direct beam or a beam that is reflected from a specular surface. A Class 3B visible wavelength laser has an output of 5 to 500 mW. UV lasers (<0.4 μm) have a relatively lower threshold for hazard Class 3B - 0.1 to 10 μW. Consequently, much longer exposures are required to produce an injury near this threshold. A Class 3B laser is considered hazardous.

4.4.2. Precautions

- Avoid eye exposure to the direct or reflected beam.
- The Laser Safety Officer and any personnel deemed appropriate by the division/section responsible for the operation of the laser must give final approval prior to operation.
- Laser training is required for persons who may be exposed to the beam while operating, maintaining, or servicing the laser. Training requests, schedules, and sign-ups are accessible in electronic form via TRAIN at the Fermilab ESH&Q Section website.
- A special laser eye exam is required for all persons who will operate, maintain, or service the laser. Contact Fermilab's Occupational Medical Office at X-3232 to schedule an appointment. An exam is required (1) prior to initial participation, (2) following a suspected laser eye injury.
- Try to reduce the hazard class by enclosing the beam path, especially for extended/repeated operations in a single location. Enclosure is typically in the best interest of the laser operator since it simplifies safety requirements and reduces the likelihood of damage to the laser set up. Enclosures must be interlocked or locked to prevent inadvertent exposure.
- Establish a controlled area during periods of unenclosed operation. Spectators should not be permitted within the controlled area unless (1) approval has been obtained from the laser operator, (2) the degree of hazard and avoidance procedures have been explained to them, and (3) appropriate protection measures have been taken. Precautions for public displays apply (see definitions).
- Wearing of appropriate laser eye protection is required at Fermilab, unless an exemption has been granted by the LSO.
- Post signs during periods of unenclosed operation.
- Unattended operation of an unenclosed system may require interlock access control and LSO approval.

- Exercise special care (1) during alignment, (2) when using invisible beams, and (3) where people who are not involved with the operation can be exposed to the beam.
- Initial laser system installation or subsequent modification, including changes in usage or location must be brought to the attention of your Division Safety Officer (DSO).

4.5 Hazard Class 4

4.5.1. Description

Any laser where diffusely scattered radiation can cause eye injury within 0.25 seconds. In other words, radiation scattered from a rough surface can cause eye damage within the time it takes to blink. Additionally, depending on output characteristics, Class 4 lasers can damage skin, ignite fires, and thermally decompose irradiated materials. A Class 4 laser presents a significant hazard that must always be treated with great care. A continuous wave laser of any wavelength with an output exceeding 0.5 W is considered to be Class 4.

4.5.2. Precautions

- Avoid eye and skin exposure to the direct or scattered beam.
- Operation requires the prior signature approval of the Laser Safety Officer and any other personnel deemed appropriate by the division/section responsible for the operation of the laser. This is typically accomplished via review and approval of written safety operating procedures that are required in any case.
- Laser training is required for persons who may be exposed to the beam while operating, maintaining, or servicing the laser. Training requests, schedules, and sign-ups are accessible in electronic form via TRAIN at the Fermilab ESH&Q Section website.
- A special laser eye exam is required for all persons who will operate, maintain, or service the laser. Contact Fermilab's Occupational Medical Office at X-3232 to schedule an appointment. An exam is required (1) prior to initial participation, (2) following a suspected laser eye injury.
- Make every effort to reduce the hazard class by enclosing the beam path, especially for extended/repeated operations in a single location. Enclosure is typically in the best interest of the laser operator since it simplifies safety requirements and reduces the likelihood of damage to the laser set up. Enclosures must be interlocked or locked to prevent inadvertent exposure.
- Establish a controlled area during periods of unenclosed operation. Spectators must not be permitted within the controlled area unless (1) approval has been obtained from the laser operator, (2) the degree of hazard and avoidance procedures have been explained to them, and (3) appropriate protection measures have been taken. Precautions for public displays apply (see definitions).
- Use an audible or visual start up warning to alert others that the laser will be activated. A laser activation warning light is required outside the entrance to each Class 4 laser room. The light is illuminated whenever the laser is in use.
- ALWAYS wear appropriate laser eye protection within the controlled area during periods of unenclosed operation. This is a critical precaution. Scattering of the beam from any surface may be able to produce an eye injury within the time you can blink.
- Post signs during periods of unenclosed operation.

- Unattended operation of an unenclosed system requires interlock access control and LSO approval. Exercise special care (1) during alignment, (2) when using invisible beams, and (3) where people who are not involved with the operation can be exposed to the beam.
- Initial laser system installation or subsequent modification, including changes in usage or location must be brought to the attention of your DSO.

4.6 Non-beam hazards

Non-beam hazards are those that do not result from exposure to a laser beam. These include the following:

- Laser components (power supplies)
- Materials used to generate the laser beam (gases, dyes, solvents)
- Materials exposed to the beam (fires, thermal decomposition products)
- Laser environment (mechanical hazards, confined spaces)

Personnel working on or near lasers with user-accessible voltage, current, or stored electrical energy shall be trained in electrical safe work practices, stored energy hazards, including capacitor bank explosion potential, and radiation hazards from equipment operating at over 500 volts. Where practical, temporary shields or guards shall be used to protect laser workers from electrical hazards.

Lasers that are not NRTL listed are subject to approval by the electrical AHJ, and this approval must be received prior to operation of the laser. See FESHM 9110 for more details.

Non-beam hazards must be considered in the use of lasers. Guidance on these hazards can be found elsewhere in this manual, in the applicable standard, from your DSO, or from the LSO.

5.0 Laser Registration

All lasers of Class 3B or 4 must be registered with the LSO. It is advisable to inform the LSO in advance of receiving the laser because the necessary precautions for such a laser may be expensive and take some time to acquire and put into place.

5.1 Steps for Completing Registration

1. Complete and forward the following Laser Registration Form.
2. Ensure that your supervisor has completed your Individual Training Needs Assessment (ITNA) and you are identified as a Fermilab Laser Class 3B or Class 4 user.
3. Take the necessary Laser Safety Training Class: FN000126.
4. Ensure the safe use of the laser by following the precautions in Section 4.4 or 4.5 of this chapter. Class 3B and 4 lasers must either be in an LSO approved laser control area (i.e. a laser lab) or must be in a Class 1 enclosure. Appropriate interlocks, signs and labels, and other control measures are required. Non-beam hazards (such as electrical or chemical) should also be considered. The LSO shall give final approval for these measures and is available to provide guidance on how to implement them. Proper PPE such as glasses shall also be approved by the LSO.
5. Place laser registration labels on laser after receipt from LSO.
6. Send laser Standard Operating Procedures to LSO for review.

7. Arrange with LSO for final field review approval of laser operations.

6.0 REFERENCES

ANSI Z136.1-2014 – American National Standard for the Safe Use of Lasers

21 CFR 1910 – FDA Performance Standards for Light-Emitting Products - *Section 1910.10 pertains to laser products.*

7.0 TECHNICAL APPENDICES

7.1 Laser safety eyewear

Laser protective eyewear is required for unenclosed operation of hazard Class 4 systems and required at Fermilab for unenclosed operation of hazard Class 3B systems, unless an exemption has been granted by the LSO. The eyewear must match the characteristics of the laser radiation; in particular, the optical density must be sufficient at the wavelength of interest, this information must be marked on the eyewear. Note that the optical density of some materials can decrease for very short pulses ($\leq 10^{-15}$ s). If working with very short pulses, you should verify that the eyewear will perform as expected. Finally, the Visible Light Transmission (VLT) of laser protective eyewear should be at least 20% to assure adequate visibility,

The optical density is calculated as follows.

$$D_\lambda = \log_{10}\left[\frac{H_p}{MPE}\right]$$

D_λ = optical density @ wavelength λ
H_p = potential eye exposure
MPE = Maximum Permissible Exposure

H_p and MPE have the same units.

Actual/Expected exposure durations should be used whenever possible. In the absence of time estimates the values shown below can be used in calculating a minimum optical density.

Suggested exposure times for eyewear design

Wavelength (μm)	Intrabeam viewing (seconds)	Diffuse viewing (seconds)
0.2 to 0.4	30,000	30,000
0.4 to 0.7	0.25	600
0.7 to 1.4	10	600
1.4 to 1,000	10	10

Determination of H_p and MPE is often a complex matter. Assistance in the determination of the optical density can be provided by the Laser Safety Officer and/or the manufacturers of the laser protective eyewear.

7.2 Laser signs and labels

Acceptable content for laser warning signs and labels is shown below. In most cases, commercial lasers will be properly labeled by the manufacturer. Signs are required for Class 3B and 4 lasers and laser systems and are recommended for Class 3R lasers and laser systems. All listed labels are

required regardless of the operational hazard class. Laser radiation hazard warning signs and labels are available from the ESH&Q Section.

In a research environment, it is not unusual to encounter several lasers, laser systems or wavelengths being used in one location. This can complicate the provision of warning information since precautions may vary with operational conditions. In particular, there may be a variety laser eyewear for different situations. There are a number of options for posting enclosures.

- Have a sign for each laser. Only post those for lasers in use.
- List all lasers or wavelengths and have a means to indicate which are in use. Try to limit the number of listed lasers or wavelengths to five per sign.
- Indicate that multiple wavelengths may be in use and personnel who wish to enter must check with the laser operator.

7.3 Laser enclosures

It is a good idea to reduce the hazard class of a laser system by enclosing the beam path, especially for extended/repeated operations in a single location. Enclosure is in the best interest of the laser operator since it simplifies safety requirements and reduces the likelihood of damage to the laser set up.

Enclosures must be locked or interlocked in order to minimize the risk of inadvertent exposure. Labeling is also required, unless failsafe interlocks are used. The enclosure must be "tight" enough such that any escaping laser radiation is not at harmful levels. For Class 4 systems, enclosures should be near-perfect since even non-specular reflections can be hazardous. Enclosures for Class 3B systems may be constructed with less conservatism. Openings can often be allowed where the beam path requires multiple non-specular reflections.

Radiations are often transported from lasers to their use locations via systems of optical fibers or piping with reflective surfaces. If the transported radiation levels are hazardous, then the rules for enclosure must also be applied to the transport system.

Where ready access to an operating laser or laser radiation is needed, the room in which the activity is taking place typically becomes the enclosure. It is often desirable to allow entry to and exit from laser rooms during laser operation. When this is done, care must be exercised to limit laser radiation levels at points of entry to the applicable Maximum Permissible Exposure (MPE). It should be kept in mind that laser rooms are subject to the same kinds of life safety requirements as other occupied spaces. This includes exiting, fire protection systems, and electrical safety.

When stable operation has been established, a laser is often put into a box so it is isolated from people. These boxes are most often constructed of aluminum. One side of the box is equipped with a piano hinge and threaded closures to serve as an access panel. The closures require a tool to open the panel. This qualifies as a "lock" for making up the enclosure. The access panel is labeled with a cautionary statement that the box contains hazardous levels of laser radiation and must only be opened upon authorization of the primary laser operator for the system. If hazardous levels of laser radiation are transmitted from the interior of the box to another location via fiber optics, they too are considered part of the enclosure.

7.4 Laser pointers

7.4.1. Background

A laser pointer is a small portable laser intended to highlight something of interest by projecting a small spot of light. To be useful for this purpose, the wavelength of the laser light must lie within the visible portion of the electromagnetic spectrum. The range is 0.4 to 0.7 μm with the peak sensitivity around 0.56 μm.

7.4.2. Selecting a laser pointer

The following recommendations apply to laser pointers that will be used to highlight something of interest by projecting a small spot of light. These devices should be limited to visible wavelength hazard Classes 2 and 3R. As a general rule, the beam should never be pointed at others, vehicles, or shiny objects. In addition, no one should be allowed to stare into the beam.

Laser pointers in hazard Classes 3B or 4, and/or those with substantial radiation in non-visible wavelengths (<0.4 μm or >0.7 μm) should not be used for routine visual highlighting purposes. This includes in particular, green laser pointers that use infrared pump light which may also be accessible. Such devices are subject to the numerous laser controls including operator training and eye exams. Though these lasers are not useful as pointers, they may be OK for qualified laser operators in well-controlled research and technical environments.

- Best choice for a laser pointer - The most practical and acceptably safe laser pointer emits at 0.532 μm (only) and has a power of 1 mW or less. This wavelength is near the peak of human visual sensitivity, so it only takes a small amount of power to produce a bright spot. On the other hand, the risk of eye injury is no greater than that for other wavelengths in the visible range. The 1 mW power level corresponds to a hazard class of 2.Acceptable choice for a laser pointer - The wavelength of the laser pointer must be in the visible portion of the electromagnetic spectrum (0.4-0.7 μm) and the output must not exceed 5 mW. This corresponds to hazard Class 3R. The nearer the wavelength is to 0.560 μm, the easier it will be to see the beam. The device must have an appropriate Class 3R laser warning label.

- Unacceptable choices for a laser pointer
  - Any device with an output exceeding hazard Class 3R is not acceptable for use as a laser pointer. This includes CW visible wavelength lasers (0.4-0.7 μm) exceeding 5 mW. Use of such a device requires that the operator receive laser safety training and a laser safety eye exam. Additional controls may apply.
  - Any device with invisible radiation (<0.4 μm or >0.7 μm) that exceed hazard Class 1 is not acceptable for use as a laser pointer. This is because potentially-exposed persons would have no way of knowing they are being irradiated by a laser. EXCEPTION: if the device emits visible radiation of sufficient intensity to discourage staring into the beam, then it is OK to use a 3R combined output limit. A visible output of 1 mW is certainly sufficient to deter staring. In fact, this is the limit for hazard Class 2. However, "sufficient visible brightness" may need to be subjectively evaluated since outputs below 1 mW may also be adequate to deter staring into the beam.

7.4.3. Laser pointer testing

The ESH&Q Section has instrumentation that can be used to measure visible and near IR wavelengths emitted from lasers. The laser power meter measures the power in both wavelength bands, then a filter is used to block the visible wavelengths. By combining these two values the power, in each band can be obtained. It should be noted that we have found laser pointers where the total output greatly exceeds labeled values, as well as laser pointers where the IR output greatly exceeds the visible output. As discussed above, these are very good reasons to reject a laser pointer for its primary intended purpose of highlighting items with a visible dot.