Fermilab
ES&H Section

April 22, 2005

TO: Jed Brown

FROM: Bill Griffing

SUBJECT: Revised FESHM Chapter 5062.1 – Lasers

Enclosed you will find revised FESHM Chapter 5062.1 - Lasers

This chapter is a complete rewrite of the existing chapter. Although procedural requirements are essentially unchanged, the content has been reorganized and simplified. Detail was also added on eyewear selection, enclosure design, ANSI standard references and laser radiation limits.

The current chapter requires registration of all unenclosed laser systems, regardless of hazard class. This draft eliminates the registration requirement for hazard class 1, 2, and 3a lasers. Although we are not subject to the State of Illinois laser regulations, this change will bring us into line with the State's registration requirements. This change also recognizes the fact that very few injuries have resulted from these lower hazard class laser systems in spite of their very widespread and unregulated presence in tools and novelties.

After final approval, please return this approval page to Liz May at MS119 for posting on the web.

Encl.

Recommended for Approval:

Jed Brown — 4/22/2005 Date

Approved:

Mike Witherell — 4/25/2005 Date

LASERS

INTRODUCTION

There are many kinds of lasers and numerous applications. In addition, the relationships between emitted radiations and harmful effects can be complicated. In order to simplify the implementation of control measures, laser radiation hazards are rated on a scale from class 1 (safe) to class 4 (dangerous). It is unlikely that a hazard class 1, 2, or 3a laser would cause an inadvertent injury. On the other hand, hazard class 3b and 4 lasers have a significant potential for causing accidental injuries. Not surprisingly, most control measures are associated with these higher class systems.

At Fermilab, class 3b and class 4 laser systems are primarily utilized in scientific applications. For example, class 3b nitrogen lasers are used as a source of pulsed ultraviolet radiation for calibrating scintillation detectors. Class 4 Nd:YAG (and similar) lasers are also used in material applications and for direct photon-particle interactions. Lasers used in commonly-encountered commercial applications such as bar code scanners, pointers, alignment systems, CD/DVD systems, and fiber optic communication systems tend to be class 2 or class 3a diode lasers.

APPLICABLE STANDARDS

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

DEFINITIONS

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.

Laser Safety Officer (LSO) – The individual who assures that laser hazards are adequately monitored, evaluated, and controlled.

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.

SPECIAL RESPONSIBILITIES

The LSO plays a Labwide consultative and oversite role in the evaluation and control of laser hazards including system classification, procedures, protective equipment, warning systems, facilities, training, and medical surveillance.

Division/Section ES&H personnel play a consultative and oversite role for laser hazards pertaining to their division/section. They are also responsible for

maintaining an inventory of hazard class 3b and class 4 lasers within their organization.

PROCEDURES

Below is a summary of Fermilab's laser safety requirements. Precautions for beam hazards are presented according to hazard class and are based on the latest version of the applicable standard, ANSI Z136.1. 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.

1. *HAZARD CLASS 1*

   a. 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 •W, depending on wavelength.

   b. 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.

2. *HAZARD CLASS 2*

   a. 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 •m).

b. 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.

3. *HAZARD CLASS 3a*

a. 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 •m or >0.7 •m), or 1 to 5 times the output of a class 2 laser at visible wavelengths (0.4 to 0.7 •m). In addition, the applicable exposure limit must not be exceeded, e.g., due to large beam diameter. For example, a class 3a 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.

b. 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. *HAZARD CLASS 3b*

a. Description

Any laser that exceeds hazard class 3a, but less than class 4. At visible and infrared wavelengths (>0.4 •m), 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 •m) have a relatively lower threshold for hazard class 3b - 0.1 to 10 •W. Consequently, much longer exposures are required to produce an injury near this threshold. A class 3b laser is considered hazardous.

b. 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 should be notified 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 ES&H Section website.
- A special laser eye exam is required for all persons who will operate, maintain, or service the laser. This exam is conducted at an offsite eye clinic. Contact Fermilab's Medical Department at X3232 to schedule an appointment. An exam is required (1) prior to initial participation, (2) following a suspected laser eye injury, and (3) upon termination from work at Fermilab.
- 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 recommended, but not required.
- Post signs during periods of unenclosed operation.
- 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/section ES&H organization.

5. *HAZARD CLASS 4*

a. 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.

b. 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 ES&H Section website.
- A special laser eye exam is required for all persons who will operate, maintain, or service the laser. This exam is conducted at an offsite eye clinic. Contact Fermilab's Medical Department at X3232 to schedule an appointment. An exam is required (1) prior to initial participation, (2) following a suspected laser eye injury, and (3) upon termination from work at Fermilab.
- 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.
- 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.
- 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/section ES&H organization.

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)

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 division/section ES&H organization, or the LSO.

TECHNICAL APPENDIX

1. *LASER SAFETY EYEWEAR*

Laser protective eyewear is required for unenclosed operation of hazard class 4 systems and recommended for unenclosed operation of hazard class 3b systems. The eyewear must match the characteristics of the laser radiation: the optical density must be sufficient at the correct wavelength. This information must be marked on the eyewear. The optical density is calculated as follows.

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

D_λ = optical density @ wavelength••
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 (•m)	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

Values are taken from ANSI Z136.1-2000.

"Intrabeam viewing" refers to direct or specularly-reflected eye exposure as might occur in an accident. "Diffuse viewing" refers to looking at scattered radiation such as occurs during many alignment activities.

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.

2. *LASER SIGNS AND LABELS*

Acceptable content for laser warning signs and labels is shown below. In most cases, commercial lasers will be labeled by the manufacturer. Signs are required for Class 3b and Class 4 lasers and laser systems and are recommended for Class 3a 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 ES&H Section.

Sign
Hazard class 3a
Visible • MPE

CAUTION
LASER RADIATION
DO NOT STARE INTO BEAM OR
VIEW DIRECTLY WITH
OPTICAL INSTRUMENTS
(Other precautionary instructions which may apply)
(Laser specifications)
CLASS 3A

Sign
Hazard class 3a
Visible > MPE

DANGER
LASER RADIATION
AVOID DIRECT EYE EXPOSURE
(Other precautionary instructions which may apply)
(Laser specifications)
CLASS 3A

Sign
Hazard class 3a
UV/IR • MPE

CAUTION
INVISIBLE LASER RADIATION
AVOID DIRECT EYE EXPOSURE
(Other precautionary instructions which may apply)
(Laser specifications)
CLASS 3A

Sign
Hazard class 3a
UV/IR > MPE

DANGER
INVISIBLE LASER RADIATION
AVOID DIRECT EYE EXPOSURE
(Other precautionary instructions which may apply)
(Laser specifications)
CLASS 3A

Sign
Hazard class 3b
(The word INVISIBLE precedes the word LASER for UV or IR radiations.)

DANGER
LASER RADIATION
AVOID DIRECT EXPOSURE
LASER TRAINING AND EYE EXAM REQUIRED
(Other precautionary instructions which may apply)
(Laser specifications)
CLASS 3B

Sign
Hazard class 4
(The word INVISIBLE precedes the word LASER for UV or IR radiations.)

DANGER
LASER RADIATION
AVOID EYE OR SKIN EXPOSURE
TO DIRECT OR SCATTERED RADIATION
LASER TRAINING AND EYE EXAM REQUIRED
(Other precautionary instructions which may apply)
(Laser specifications)
CLASS 4

Label
Classification/Inventory

NOTICE
THIS DEVICE HAS A LASER
RADIATION HAZARD CLASS
OF *(System class as used)*
ASSESSED ON *(Date)*
BY *(Name)*
X4646 ES&H SECTION
(Laser sequence number)

Label
Laser enclosure

CAUTION
THIS DEVICE CONTAINS
A CLASS *(3B OR 4)* LASER
DO NOT OPEN WITHOUT
AUTHORIZATION FROM
(Name of designated person)

Label
Laser fiber optic

CAUTION
HAZARDOUS LASER RADIATION
WHEN DISCONNECTED
DO NOT DISCONNECT WITHOUT
AUTHORIZATION FROM
(Name of designated person)

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, the enclosure should be near-perfect since even non-specular reflections can be very 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.

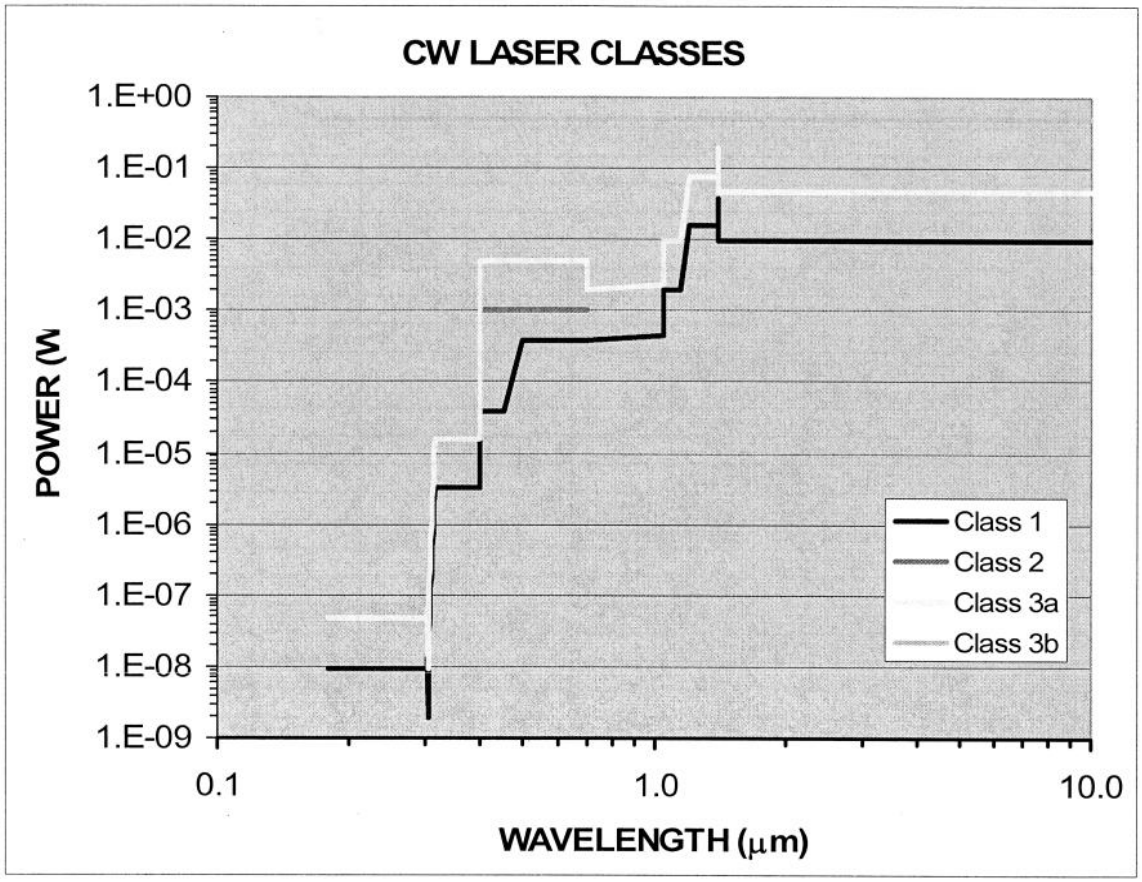
Radiations are often transported from lasers to their use locations via systems of optical fibers or piping with reflective surfaces. If the transported radiation levels are hazardous, then the rules for enclosure must also be applied to the transport system.

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. When stable operation has been established, the 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.

Control #	Section #	ANSI Z136.1-2000 Required controls (including section references) Control	1	2	3a	3b	4		Engineering control	Administrative or procedural control
1	4.3.1	Protective housing	X	X	X	X	X		X	
2	4.3.1.1	Without protective housing	LSO	LSO	LSO	LSO	LSO		X	
3	4.3.2	Interlocks on protective housing	Δ	Δ	Δ	X	X		X	
4	4.3.3	Service access panel	Δ	Δ	Δ	X	X		X	
5	4.3.4	Key control				*	X		X	
6	4.3.5.1	Viewing portals		MPE	MPE	MPE	MPE		X	
7	4.3.5.2	Collecting optics	MPE	MPE	MPE	MPE	MPE		X	
8	4.3.6.1	Totally open beam path				NHZ	NHZ		X	
9	4.3.6.2	Limited open beam path				NHZ	NHZ		X	
10	4.3.6.3	Enclosed beam path	if no H	if no H	if no H	if no H	if no H		X	
11	4.3.7	Remote interlock connector				*	X		X	
12	4.3.8	Beam stop or attenuator				*	X		X	
13	4.3.9.4	Activation warning systems				*	X		X	
14	4.3.9.1	Emission delay					X		X	
15	4.3.10	Indoor laser controlled area				X	X		X	
16	4.3.10.1	Class 3b indoor laser controlled area				X			X	
17	4.3.10.2	Class 4 indoor laser controlled area					X		X	
18	4.3.11	Laser outdoor controls				X	X		X	
19	4.3.11.2	Laser in navigable airspace			*	*	*		X	
20	4.3.12	Temporary laser controlled area	Δ MPE	Δ MPE	Δ MPE				X	
21	4.3.13	Remote firing and monitoring					*		X	
22	4.3.14	Labels	X	X	X	X	X		X	
23	4.7	Labels	X	X	X	X	X		X	
24	4.3.9	Area posting			*	X	X		X	
25	4.4.1	Standard operating procedures				*	X			X
26	4.4.2	Output emission limitations			LSO	LSO	LSO			X
27	4.4.3	Education and training		*	*	X	X			X
28	4.4.4	Authorized personnel				X	X			X
29	4.4.5	Alignment procedures		X	X	X	X			X
30	4.6	Protective equipment				*	X			X
31	4.4.6	Spectator				*	X			X
32	4.4.7	Service personnel	Δ	Δ	Δ	X	X			X
33	4.5.1	Demonstration with general public	inv MPE	X	X	X	X			X
34	4.5.2	Laser optical fiber systems	MPE	MPE	MPE	X	X			X
35	4.5.3	Laser robotic installations				X	X			X
36	4.6.2	Eye protection				* MPE	X			X
37	4.6.3	Protective windows				NHZ	NHZ			X
38	4.6.4	Protective barriers and curtains				*	*			X
39	4.6.6	Skin protection				MPE	MPE			X
40	4.6.7	Other protective equipment	LSO	LSO	LSO	LSO	LSO			X
41	4.7	Warning signs and labels (designs)		*	*	NHZ	NHZ			X
42	4.4.7	Service and repairs	LSO	LSO	LSO	LSO	LSO			X
43	4.1.2	Modifications and laser systems	LSO	LSO	LSO	LSO	LSO			X

X	Shall
*	Should
Δ	Shall if enclosed 3b or 4
MPE	Shall if MPE exceeded
NHZ	Shall, requires NHZ analysis
if no H	Shall, if no housing
LSO	LSO discetion

Maximum continuous wave laser power
as a function of wavelength and hazard class
(Interpreted from ANSI Z136.1-2000 values for MPE)



Power to reach ocular MPE
as a function of wavelength and exposure time
(Interpreted from ANSI Z136.1-2000 values for MPE)