NCCentral UNIVERSITY
Environmental Health and Safety

Laser Safety Manual

Version # 1.0

Contents

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Approved by: K. Long-Witter, Director

I. Regulations, Standards, and Policies

The Occupational Safety and Health Administration (OSHA) has a limited number of regulations that are specific to the use of lasers in the work place, but does provide guidance on the safe use of laser and recognizes the ASC-Z136 series of standards as providing guidance on laser worker protection. For more information see OSHA Laser Hazards and OSHA Technical Manual (OTM) Section III: Chapter 6. The NCCU policy on laser safety requires that all lasers and laser systems be operated in accordance with the American National Standards Institute (ANSI) Z136.1 2000, "the Safe Use of Lasers;" and other applicable federal and state regulations.

II. Purpose

The primary objective of the NCCU laser safety program is to ensure that no laser radiation in excess of the maximum permissible exposure (MPE) limit reaches the human eye or skin. Additionally, the program is designed to ensure that adequate protection against collateral hazards is provided. These collateral hazards include the risk of electrical shock, fire hazard from a beam or from use of dyes and solvents, and chemical exposures from use of chemicals and vaporization of targets.

This manual is also a guide to assist laser users in complying with relevant laser regulations. The information found in this manual and the associated documents serves as a reference guide through which all university personnel may familiarize themselves with the policies and procedures for the safe use of lasers.

The objectives of the NCCU Laser Safety Program are to:

- Identify potential health and safety hazards associated with lasers, laser systems and laser operations.
- Provide suitable means for the evaluation and control of laser hazards.
- Provide guidance of the safe use of lasers, laser systems and laser operations.
- Investigate all laser accidents and institute immediate appropriate corrective actions to prevent
- reoccurrence.
- Provide guidance on compliance with relevant laser regulations.

III. Scope

The policies and procedures contained in this manual apply to all departments, laboratories, and persons using or possessing Class 3B and 4 lasers. Lower class lasers products that contain a laser that produces an output which qualifies it as a Class 3B or 4 laser system, often referred to as embedded lasers, are also covered by this manual. The policies and procedures found in this manual apply to all NCCU facilities and properties regardless of location. The EHS (ehs@nccu.edu; 919-530-7125) shall be contacted to confirm whether or not a laser or laser system is classified as Class 3B or 4.

IV. Emergency Numbers

Agency	Phone	Hours
Emergency	911	24 hours
Environmental Health & Safety	919-530-7125	8:00 a.m. – 5:00 p.m.
University Police	919-530-6106 or 911	24 hours
Work related injuries	919-530-6106 or 911	24 hours
NC Poison Control Center	1-800-848-6946	24 hours

V. Definitions and Abbreviations

Accessible emission limit - the maximum accessible emission level permitted within a particular class of laser.

Collateral radiation - any electronic product radiation, except laser radiation, emitted by a laser product as a result of the operation of the laser(s) or any component of the laser product that is physically necessary for the operation of the laser(s).

Invisible radiation - laser or collateral radiation having wavelengths of equal to or greater than 180 nm but less than or equal to 400 nm or greater than 710 nm but less than or equal to 1 mm.

Laser - **L**ight **A**mplification by **S**timulated **E**missions of **R**adiation. A laser is a device consisting of an optical cavity, normally with mirrors at the ends, a gain medium such as crystal, glass, liquid, gas or dye, and energy is source. When activated this device will produce an intense beam of light with the unique properties of coherency, directionality and monochromaticity, e.g. (laser light).

Laser energy source - any device intended for use in conjunction with a laser to supply energy for the operation of the laser. General energy sources such as electrical supply mains or batteries shall not be considered to constitute laser energy sources.

Laser product - any device that incorporates or is intended to incorporate a laser or a laser system. This is also a legal term in the U.S. See FDA-CDRH: 21 CFR 1040.10.

Laser system - a laser in combination with an appropriate laser energy source with or without additional incorporated components.

Protective housing - those portions of a laser product which are designed to prevent human access to laser or collateral radiation in excess of the prescribed accessible emission limits.

Safety interlock - a device associated with the protective housing of a laser product to prevent human access to excessive radiation.

VI. Responsibilities

Individuals, who are responsible for laboratories or work areas where Class 3B or 4 lasers are located or used, and supervisors, employees, students, and other personnel, who work with or around Class 3B or 4 lasers, are responsible for compliance with the policies and requirements found in this manual. The safety awareness of all personnel who operate lasers is the most important aspects of a laser safety program.

A. Environmental Health and Safety

- Is responsible for overseeing the University laser safety program
- Has the authority to suspend, restrict, and terminate the operation of a laser/laser system if the laser hazard controls are inadequate or presents an imminent danger
- Maintain records of all Class 3b and 4 lasers and laser operators
- Provide assistance in evaluating and controlling hazards:
    - Provide appropriate warning signs for posting
    - Provide assistance to Principal Investigator (PI)/Authorized Laser User (ALU) on establishing appropriate controlled areas
    - Calculate Maximum Permissible Exposure (MPE) and the Nominal Hazard Zone (NHZ) as necessary and appropriate
    - Provide guidance on proper protective eye wear
- Provide laser safety training for new users
- Participate in accident investigations involving lasers
- Periodically audit the departmental Laser Safety Program

B. Principal Investigator/Authorized Laser Users

The PI/ALU is an individual directly responsible for the acquisition, use and maintenance of a particular laser/laser system. PI/ALU are responsible for:

- Notifying the EHS prior to the acquisition or fabrication of a new laser so that a preliminary safety review and laser inventory update can be made.
- Ensuring that the information on laser/laser system is provided in the Lab-Specific Safety Plan (LSP)
- Ensuring that Laser Standard Operating Procedures (LSOPs) are written for Class 3B and all Class 4 lasers and included into LSP.
- Ensuring that all laser operators complete laser safety training before they are authorized to operate any laser.
- Establishing and maintaining a current list of personnel approved to operate specific types of Class 3b or 4 lasers under their supervision and providing a copy of the list to the EHS.
- Immediately notifying EHS in the event of a suspected overexposure to the output beam from a Class 3b or 4 lasers.

C. Laser Operators

All personnel operating lasers must follow general laser safety training from EHS and any manufacturer's laser-specific safety guidelines for the laser they are operating.

D. Unaffiliated Personnel (visitors, observers, minors, etc.)

It is the policy of the NCCU EHS to require the same level of laser laboratory safety for all personnel in a laser facility a is required for laser users. All unaffiliated personnel are to be escorted by either the PI/ALU or by a Laser Operator and it is the responsibility of the escort to provide unaffiliated individuals with an appropriate safety orientation covering the hazards in the laser laboratory. The escort shall also provide appropriate PPE and require the unaffiliated personnel to use that safety equipment.

VII. Laser Classification

Lasers are divided into multiple classes depending upon the power or energy of the beam and the wavelength of the emitted radiation. Laser classification is based on the laser's potential for causing immediate injury to the eye or skin and/or potential for causing fires from direct exposure to the beam or from reflections from diffuse reflective surfaces. The manufacturer provides the classification for most lasers.

A. Class 1 Lasers

Class 1 lasers are considered to be incapable of producing damaging radiation levels, and are therefore exempt from most control measures or other forms of surveillance. Example: some laser printers, disk readers/writers.

B. Class 2 Lasers

Class 2 lasers emit radiation in the visible portion of the spectrum (400 – 700 nm), and protection is normally afforded by the normal human aversion response (blink reflex) to bright radiant sources. They may be hazardous if viewed directly for extended periods of time. Example: laser pointers, bar-code scanners, non-contact thermometers, image projector, leveling devices.

C. Class 3A Lasers

Class 3a lasers are those that normally would not produce injury if viewed only momentarily with the unaided eye. They may present a hazard if viewed using collecting optics, e.g., telescopes, microscopes, or binoculars or for long duration. Example: HeNe lasers above 1 mW but not exceeding 5 mW radiant power; some laser pointers.

D. Class 3B Lasers

Class 3B lasers have energy outputs between 5 and 500 mW and like the 3A class can emit photons from the UV to far infrared, of pulsed or continuous wave emission. These lasers are hazard to the eye or skin from direct and specular reflection viewing conditions; as such eye protection is required, as well as barriers, to prevent exposure to the beam. Although hazardous when viewed directly even for momentary exposures, class 3B lasers are normally not a diffuse reflection or fire hazard. Examples: lasers used in research, medical treatments.

E. Class 4 Lasers

Class 4 lasers are a hazard to the eye from the direct beam and specular reflections and sometimes even from diffuse reflections. Class 4 lasers can also start fires and can damage skin. They can produce laser generated air contaminants (LGAC) and hazardous plasma radiation, upon interaction with a wide range of materials. **Due to their high degree of hazards; class 4 lasers require eye protection, beam/room barriers, and warning systems.** Example: Lasers operating at power levels greater than 500 mW for continuous wave lasers or greater than 0.03 J for a pulsed system (e.g., lasers used in the research, manufacturing, medical treatment).

F. Embedded Class 3B or 4 Lasers

A laser product that is designated Class 1, 2, or 3A (3R) for normal operation, but contains a Class 3B or 4 lasers is termed an embedded laser system. This type of laser product is given a lower classification due to the engineering features that limit access to the laser emission during normal operations. Examples of these type of lasers are: cutters, cell sorters, flow cytometers, stereo lithography systems.

VIII. Laser Acquisition, Transfer, and Disposal

A. Acquisition

All lasers, laser systems, or embedded lasers purchased or loaned for use at NCCU must be FDA-CDRH approved. Individuals needing to obtain a Class 3B/4 laser or laser system, must contact the EHS prior to acquiring the laser or laser system. The acquisition of a laser or an embedded laser system that require special utilities, venting or cooling, may require a facilities modification request for proper installation. The PI/ALU needs to complete the Equipment & Instrumentation Pre-Purchase Checklist before laser or laser system ordering. If facilities modification is needed, the PI/ALU must also complete the Facility Modification Request Form. This will permit appropriate preplanning to assure that all hazard controls are in place prior to the laser or laser systems arrival on campus. Being proactive about your laser purchase will permit appropriate budgeting, facilities modification e.g. (laboratory layout, entryway controls, etc.), and other necessary measures to be understood and completed, such as training.

B. Transfer

The PI/ALU must contact the EHS, prior to transferring ownership of a laser to another employee or to a new location, either within or outside of NCCU. This is necessary to ensure that all hazards are addressed prior to operation of the laser by its new owner or at its new location. Additionally, these lasers will need to be transferred to the new owner or removed from the NCCU laser inventory, if it leaves the university.

C. Disposal

Contact the EHS prior to disposing of a Class 3B/4 laser or any equipment that contains an embedded Class 3B/4 laser. These lasers and laser containing equipment must be rendered "inoperable" prior to disposal via any mode of disposal. Please note some types of lasers contain hazardous materials, and they must be disposed of as unwanted materials. Additionally, lasers that will be transferred to Central Receiving and Stores for surplus or disposed of as hazardous material will need to be removed from the NCCU laser inventory.

IX. Control Measures

Effective hazard control starts with the most effective, i.e., elimination of the hazard and proceeds to personal protective equipment the least effective. If elimination or substitution of Class 3B/4 lasers or laser systems is not possible, engineering, administrative and PPE control measures are used to minimize the risk of serious injury, and property damage.

A. Laser Hazard Evaluation

Hazard reviews are intended to minimize the risk of serious injury, property damage, and the associated impact of these events, by reviewing hazardous equipment and processes to eliminate unreasonable risks at the design stage. A hazard review must be performed:

- On all new Class 3B/4 laser installations
- When setup of a relocated laser, regardless of the equipment's age
- When a significant change is made to the original laser setup (e.g., moving a laser to a new lab, major changes in an open beam path, addition of "new" hazards to the beam path, new material beam interactions that generate gases or vapors, or other activities that require a change in engineering controls or operating procedures).

A hazard assessment includes:

- Properties of the laser(s) (power, wavelength, etc.)
- Location environment
- Existing controls (emergency, etc.)
- Intended work practices and procedures
- Potential exposures

Results of the hazard review will serve as the basis for laser laboratory design, installation and operation of the laser/laser system. Additionally, the information obtained from the hazard review should be incorporated into a Laser Standard Operating Procedure (SOP).

B. Safety Requirements for Class 3B and 4 Lasers

Requirement	Laser Class 3B	Laser Class 4

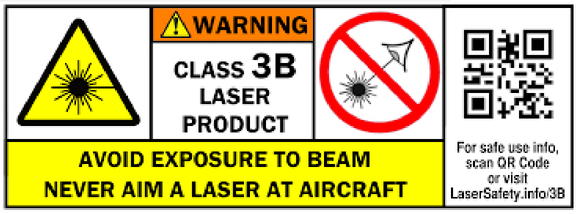
Warning label	✓	✓
Registration with EHS	✓	✓
Warning door signage	✓	✓
EHS Notification of Laser Requisition*	✓	✓
General Laser Safety Training	✓	✓
Laser-Specific Safety Training	✓	✓
Laser SOP	Recommended	✓
Controlled Area	✓	✓
Laser Key Control	Recommended	✓

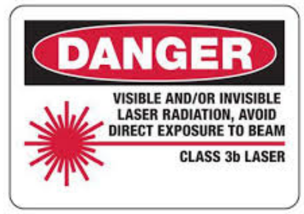
* Notification applies when a laser setup is remodeled significantly whereby the original hazards assessment or SOP is no longer valid.

1. Class 3B Requirements

- Do not aim the laser at an individual's eyes.
- Permit only properly trained and authorized personnel to operate the laser.
- Enclose as much of the beam path as possible.
- Place appropriate beam stops at the end(s) of the useful beam path(s).
- Restrict the access of unauthorized personnel; control spectators.
- Operate the laser in a controlled area (as defined by the PI/ALU and EHS or in the SOP), unless the beam path is totally enclosed.
- Employ a warning light or buzzer to indicate laser operation if appropriate, especially for invisible (UV or IR) lasers.
- Locate the plane of the laser beam and associated optical devices well above or below the eye level of observers whenever possible.
- Firmly mount the laser to ensure the beam does not stray from the intended path.
- Use proper eye protection if eye exposure to the direct beam or a specular reflection is possible.
- Do not view the beam or its specular reflection with collecting optics without sufficient eye protection.
- Remove all unnecessary reflective surfaces from the area of the beam path.
- Should develop SOP for laser operation
- Should incorporate key control of a master switch that can terminate beam operations.

Label examples:



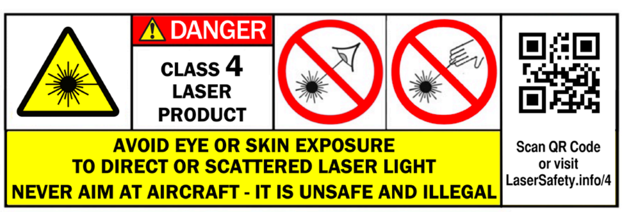


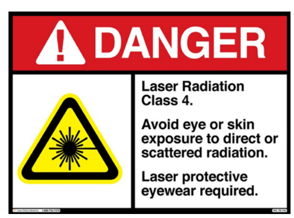
2. Class 4 Requirements

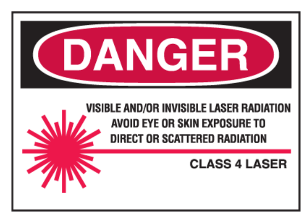
Includes all Class 3B requirements, plus following:

- Shall develop an SOP for laser operations.
- Shall incorporate key control of master switch that can terminate beam operations.
- Entryway safety controls shall be designed to allow both rapid egress by laser personnel at all times and admittance to the controlled area under emergency conditions.
- Shall provide for and ensure use of proper eye protection for everyone within the controlled area.
- Use appropriate shielding between personnel and any beam having sufficient irradiance to pose a serious skin or fire hazard.
- Use remote viewing methods where feasible (e.g. video monitoring) to accomplish any necessary viewing of the beam.
- Construct non-specular absorbent beam stops of fire resistant material.
- Use adequate ventilation and vented enclosures when dealing with excimer lasers due to the presence of toxic gases and fumes.

Label examples:







C. Converting Laser/Laser System to a Class 1 Laser

Any laser/laser system can be converted to a Class 1 embedded laser/laser system. Prior to constructing/operating Class 1 embedded laser/laser system you must contact the EHS to insure that all appropriate control measures are in place. The following controls need to be incorporated into the enclosure design:

1. Enclosure

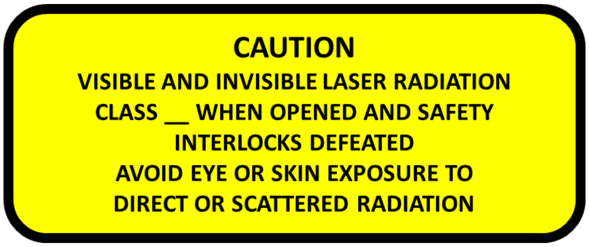
- The laser/laser system must be completely housed within a protective enclosure that prevents escape of laser radiation above the MPE.
- The protective enclosure must be constructed of material capable of withstanding direct laser beam exposure.
- The protective enclosure must prevent personnel from accessing the laser emission during normal operations.
- All view ports must be rated for the emission of the enclosed laser and prevent exposure to laser radiation above the MPE.
- All penetrations through the enclosure must be sealed to prevent access to laser radiation above the MPE.
- The enclosure must allow access to the laser controls without exposing personnel to laser radiation above the MPE.
- A laser emission indicator must be fitted to the exterior of the enclosure, if there is not an emission indicator on the laser controls.

2. Interlocks

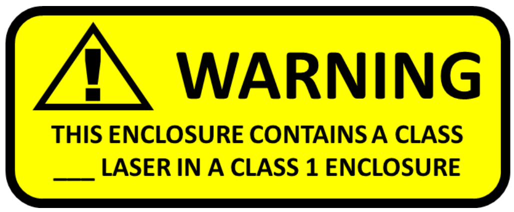
- Interlocks/interlock connections are to be installed wherever a protective enclosure can be opened, removed or altered in such a manner as to allow access to the laser emission.
- Activation of any interlock point must disable the laser emission, such that it prevents exposure to laser energy above the MPE.
- The interlocks must be of "Fail-Safe" design, meaning that if any interlock/interlock connection should fail to operator laser emissions will be disabled.
- The laser/laser system must not 'automatically' restart after an interruption due to remote interlock activation or from an interruption for more than 5 seconds due to unexpected loss of main electrical power.
- Enclosure interlock(s) must not be defeatable; any work requiring access to laser radiation above the MPE must be conducted in a laser control area suitable for the maximum emission of the laser.

3. Warning Signs and Labels

The enclosure must be labeled with sign(s) that indicate the level of hazard when the enclosure is opened and the interlocks are disabled. Examples of such a label is shown below:



A warning label shall be affixed to the enclosure indicating that a laser of Class greater than Class 1 is contained within the Class 1 enclosure. An example of such a label is shown below:



D. Special Requirements for Invisible Laser Beams

Since infrared (IR) and ultraviolet (UV) wavelengths are normally invisible to human eyes, they possess a higher hazard potential than visible light lasers. Therefore, the use of laser eyewear that will protect against the exposure is required at all times during laser operations.

1. Infrared Lasers

- The collimated beam from a Class 3 laser should be terminated by a highly absorbent backstop wherever practicable. Many surfaces which appear dull visually can act as reflectors of IR.
- A class 4 laser beam should be terminated in a fire resistant material whenever practicable. Periodic inspection of the absorbent material is required since many materials degrade with use.

2. Ultraviolet Lasers

- Exposure to UV should be minimized by using shield material that attenuates the radiation to levels below the appropriate MPE for the specific wavelength.
- UV radiation causes photochemical reaction in the eyes and the skin, as well as in materials that are found in laboratories. The latter may cause hazardous by-products such as ozone and skin sensitizing agents. The use of long-sleeved coats, gloves, and face protectors is recommended.

E. Standard Operating Procedure (SOP)

Written Standard Operating Procedures are required for use of all Class 3B/4 lasers and Class 1 laser product that contain class 3B/4 lasers. Laser Principal Investigator/Supervisor is responsible for creating these SOP's. A safe SOP shall outline the requirements, which are to be reviewed by all laser users/operators, for normal operation of the laser and any hazards that may be encountered during normal operation. The SOP shall explain how to minimize any hazards and how to respond in the event of an emergency. Laser SOPs shall be included in to the Laboratory-Specific Safety Plan. A Laser SOP template (Appendix A) covers the following required areas:

- A description of the laser(s)
- All laser(s) beam paths from laser to end use, including all stray beam/unwanted reflection
- All protective equipment used with the laser(s), including laser eye protection
- All beam and non-beam hazards and the methods of mitigation for these hazards
- Start up, shut-down, alignments, service, and maintenance procedures
- Emergency procedures
- Who is authorized to use the laser, their attestation to having read and understood the SOP

Completed SOP should be submitted to the EHS for review and approval. After the initial review, the research group is required to conduct annual reviews of all their SOP's. A copy of all SOP's should be available for review by laser users/operators and EHS.

E. Access Controls

Laser PI/ALU is responsible for controlling access to their Class 3B/4 laser(s) at all times. This is very important whenever the laser is in operation; access to laser facilities is restricted to authorized laser personnel (users/operators) or persons being escorted by them. The physical means by which access control achieved is by the requirement for locked or interlocked laser facility entryway(s). Warning signs at laser laboratory entrances aid in controlling who may access the facility but are not considered effective at controlling access.

F. Beam Management

Laser beam management is the process of identifying and controlling hazardous laser emissions. Laser PI/ALU is responsible for:

- Seeing that all laser beam(s) are restricted to the immediate location of use.
- Laser beams must be confined to the optical table, enclosing container, or use area.
- Beams paths should be enclosed, from the laser aperture to the use point, whenever practical. Whole table enclosure, table curbing, beam tubes and covers, not only increase safety and beam management, they reduce contamination of optics.
- All unused laser emissions must terminate in beam stops/barriers.
- All beam management items must be constructed of non-combustible materials.
- All of the laser personnel are responsible for verifying through survey that appropriate beam management is practiced.

X. Personal Protective Equipment (PPE)

All personnel must receive training on proper PPE; how to use, to fit, to maintain, and when to retire it, for the hazard it is designed for. Personnel must also understand all the limitations of their PPE. Minimum protective equipment for work in a laboratory includes a lab coat, protective eyewear, long pants and closed toe shoes.

A. Laser Eye Protection

Eye safety is the number one concern when working with or near a laser. The pulse of a laser is so fast; it can cause severe damage to the eye in a flash of a second. Though the injuries are rare, they are permanent. Several types of injuries can occur to retina, cornea and lens damage: (i) thermal burn, (ii) acoustic and electromagnetic damage, and (iii) photochemical damage.

Laser Eye Protection (LEP) is required whenever persons are within the nominal hazard zone (NHZ). The NHZ is considered to be the entry area where the maximum permissible exposure (MPE) limit is exceeded. LEP must be of the correct optical density for the specific wavelength(s) of each laser in use. Unfortunately, there is not a LEP that can provide protection against all of the electromagnetic spectrum. Eyewear must be specifically selected to withstand either direct or diffusely scattered beams and shall meet all provisions of ANSI Z87.1-2020. Factors in selecting appropriate eyewear:

- Laser power and/or pulse energy
- Wavelength(s) of laser output
- Potential for multi-wavelength operation
- Radiant exposure or irradiance levels for which protection (worst case) is required
- Exposure time criteria
- Maximum permissible exposure
- Optical density requirement of eyewear filters at laser output wavelength
- Angular dependence of protection afforded
- Visible light transmission requirement and assessment of the effect of the eyewear on the ability to perform tasks while wearing the eyewear
- Need for side-shield protection and maximum peripheral vision requirement
- Radiant exposure or irradiance and the corresponding time factors at which laser safety filter characteristics change occurs, including transient bleaching especially for ultra-short pulse lengths
- Need for prescription glasses
- Comfort and fit
- Degradation of filter media, such as photo bleaching
- Strength of materials (resistance to mechanical trauma and shock)
- Capability of the front surface to produce a hazardous specular reflection
- Requirement for anti-fogging design or coatings

Eyewear must be inspected before each use, and replaced if necessary, to maintain the eyewear in good condition. Contact EHS for assistance in selecting protective eyewear.

B. Laser Skin Protection

Skin protection can best be achieved through engineering controls. If potential skin damaging exposures exist, skin covers and or "sun screen" creams are recommended. Minimize exposure to UV radiation by using beam shields and clothing (opaque gloves, face shield, tightly woven fabrics, laboratory jacket or coat) which attenuate the radiation to levels below the MPE for specific UV wavelengths. Consider flame-retardant materials for Class 4 lasers. Special attention must be given to the possibility of producing undesirable reactions in the presence of UV radiation (formation of skin sensitizing agents, ozone, etc.). Infrared laser can also damage exposed skin, covering the hands with thermal gloves may be necessary. A hazard assessment will help in identifying what types of skin protection that are needed to mitigate laser hazards.

Summary of Basic Biological Effects of Light to the Eye and Skin

Wavelength Regions	Consequence to the Eye	Consequence to the Skin
Ultraviolet C (100 – 280 nm)	Photokeratitis (inflammation of the cornea, similar to sunburn)	Erythema (sunburn), accelerated skin aging, skin cancer
Ultraviolet B (280 – 315 nm)	Photokeratitis (inflammation of the cornea, similar to sunburn)	Erythema (sunburn), increased pigmentation, accelerated aging, cancer
Ultraviolet A (315 – 400 nm)	Photochemical cataract (clouding of the lens)	Erythema (sunburn), pigment darkening, skin burn
Visible (400 – 700 nm)	Photochemical, thermal retinal injury	Photosensitive reactions, skin burn
Near Infrared A (700 – 1,400 nm)	Cataract, retinal burns	Skin burn
Mid Infrared B (1,400 – 3,000 nm)	Corneal burn, aqueous flare (protein in aqueous humor), thermal cataract	Skin burn
Far Infrared C (3,000 nm – 1 mm)	Corneal burn	Skin burn

XI. Non-Beam/Ancillary Hazards

Non-laser beams or ancillary hazards arise from the use of a laser/laser system and are often overlooked by the laser user. While the hazards of laser beams are the most commonly recognized hazard, other hazards pose equal or possibly greater risk of injury or death. Non-beam hazards can be placed into four broad categories, Biological, Chemical, Ergonomic and Physical. A laser/laser system may introduce one or many non-beam hazards to the laser laboratory. All non-beam hazards that are introduced by a laser/laser system shall be addressed in the SOP.

A. Biological

Biohazards can arise from either handling or laser processing biological materials. All laboratory personnel who will work with biological material should be familiar with university Biosafety requirements.

1. Laser Generated Air Contaminants

The interaction of a laser beam with biological materials may produce toxic particles, chemical vapors/gases, and infectious aerosols. Class 4 lasers are most likely to produce toxic interactions with biological material, but Class 3B can also produce them particularly when beam energies exceed 100 W/cm^2. Toxic products resulting from laser processing must be properly controlled using adequate ventilation and filtration, at the point of generation.

2. Infectious Material

Laser treatments involving infectious organisms can result in the spread of those organisms by creating an aerosol. Although the amount of irradiance necessary to produce an aerosol is high, laboratory studies have shown that some infectious organisms can survive these energies. The Laser PI/ALU must consult with the EHS prior to any work being conducted with infectious material. Additionally, whenever laser processing potentially infectious materials is to occur the use of adequate bio-filtration and ventilation, at the point of generation is required.

B. Chemical

In addition to the components of some lasers / laser systems being hazardous, chemical reactions can occur when the laser beam interacts with materials producing hazardous compounds. Not all laser beam interactions produce hazardous or toxic by-products. Components of laser/laser systems that can be hazards are: laser dyes, gases, and the composition of electrical/mechanical elements within the laser. Safety Data Sheets (SDSs) should be read and understood by all laser personnel for any chemical handled in the laser laboratory. Additionally, laser personnel should review the laser/laser system manuals for information concerning toxic components within their equipment. SDS's will supply appropriate information pertaining to the toxicity, personal protective equipment needed, storage requirements, and disposal recommendations.

1. Laser Generated Air Contaminants

The interaction of the Class 3B and 4 laser beam with target materials may produce toxic dusts, chemical vapors/gases. This is particularly true during material processing (welding, cutting, vapor deposition, etc.). This will most often occur when the target irradiance reaches a given threshold, generally ≥100 W/cm^2, target materials (including plastics, composites, metals and tissues) may liberate toxic and noxious airborne contaminants. Any potentially toxic products resulting from laser processing must be properly controlled using adequate ventilation and filtration, at the point of generation.

2. Gases

Some types of lasers use either pure gases or gas mixtures as the lasing medium, these may be in the form of a sealed laser tube or supplied from an external source, both of which can be hazardous. The high pressure of the compressed or cryogenic gas that are stored in the cylinders translates into substantial potential energy, which if released in uncontrolled manner (e.g., broken nozzle/regulator), can become an unguided missile. Compressed gas cylinders must be properly restrained at all times to prevent damage to the nozzle/regulator. More information on the proper storage, use and handling of gas cylinders can be found in the Laboratory Safety Manual.

The gases themselves may present a variety of hazards if they leak from the cylinder. Depending on the gas, it may be toxic, corrosive, flammable, or extremely cold. Laser PI/ALU should refer to the manufactures SDS for detailed information on any gas used in a laboratory.

3. Cryogenic materials

Cryogenic liquids (e.g., nitrogen, helium, argon and oxygen) are used for cooling certain lasers and treating test samples in laser laboratories. The very nature of these materials is that they evaporate; in a poorly ventilated space, oxygen depletion can occur, resulting in an asphyxiation hazard. Adequate ventilation must be provided in all locations that cryogenic liquids are stored or used. Oxygen deficiency monitors may be required in lasers laboratories using cryogenic liquids. Cryogenic Dewar's are potentially explosive if venting ports are plugged or ice builds up on them. Special types of valves, connections and tubing which are designed for use with cryogenic liquids are required. Condensation of oxygen from the atmosphere can occur with any cryogenic liquid colder than 90 K (-183.0 °C; -297.4 °F) and presents a serious fire/explosion hazard if it is exposed to any organic material. These extremely cold liquids can freeze materials/tissues rapidly; any moist tissue (eyes, mouth, etc.) will be damaged nearly instantaneously upon contact. Handling cryogenic liquids therefore requires additional PPE beyond the basic laboratory requirements, and includes a full-face shield over safety glasses, loose-fitting thermal insulated or leather gloves, long sleeved shirts and pants without cuffs or openings exposing skin. Contact EHS if your research involves the use of cryogenic liquids.

4. Nanoparticles

In most cases, Laser Generated Air Contaminants whether chemical or biological in origin will contain substantial amounts of nanoparticles. Laser based research on nanoparticles can pose a hazard to humans and appropriate chemical handling methods should be used. Research is still in the early stages as to the effects that nanoparticles have on human health, as such using methods to remove any potentially hazardous particles through adequate ventilation and filtration, at the point of generation is recommended. Additional information on nanoparticles can be found in the Laboratory Safety Manual.

C. Ergonomic

A properly designed laser laboratory will be based upon a good ergonomic layout, which will lead to improved human performance and productivity. Unfortunately, ergonomically designed laser research laboratories are a very rare thing. Most laser laboratories face an issues with walkway spacing, reach distances, workstation positions, overhead objects, and storage spaces.

1. Equipment concerns

Where the laser and its support equipment are placed in the laser facility can play a very large role in the productivity of the laser users as well as the quality of data collected. Good design will also prevent unnecessary safety issues. Cables, protruding equipment, create tripping hazards, over hanging shelves and cabinets create obstructions for equipment and humans. Equipment that is difficult to operate or service because of poor location makes the laser laboratory unnecessarily hazardous. Poor lighting can compound issues of equipment location and reduce operator performance greatly.

2. Operator concerns

The most pressing concerns for laser operators are the locations of equipment that will need to be addressed during the operation of the laser/laser system. Workstations that are located far from the point of use will mean operators constantly need to leave the workstation to make the required instrument adjustments. In contrast, workstations located at the point of measurement present the operator with direct beam hazards. Both of these conditions and the hazards either between measurement points or at them present constraints that should be addressed in the SOP.

D. Physical

Physical hazards in the laser laboratory are those that the laser or laser system introduce into, by the device itself or by how it is used. The laser operator needs to be aware of these hazards and take measures to control these hazards.

1. Electrical

Electrocution while working with high voltage can be lethal. Electrocution has been reported as the leading cause of death for laser operators. Electrical hazards are present during installation, maintenance, or service, even if the laser/laser system is turned off, as some components can store electrical energy (capacitors). All work on the electrical system of laser shall be preform only by trained and qualified technicians, with the laser power disconnected. All high voltage electrical contacts must be properly covered, to prevent possible accidental exposure and capacitors need to be correctly discharged prior to performing service. Laser systems that incorporate the use of a water-cooling system should be treated with great caution. The combination of water and electrical hazards greatly increases the risk of serious injury. Laser systems that permit access to components at lethal levels must be interlocked; older laser systems may not have interlocks on protective covers.

2. Noise

Laser laboratories can be noisy at times from compressors, flash lamp discharges, beam target interactions, etc. If there are enough sources of noise, it may become uncomfortable or difficult for the occupants to communicate or hear audible warning alarms. Where possible noise levels should be reduced to levels that permit normal conversation. If the noise level seems unpleasant or painful, contact EHS to request that a noise survey be done.

3. Collateral radiation

Laser and laser systems may produce hazardous collateral radiation of various types. These hazards may arise from the equipment itself or from the laser beam interaction with targets. Manufactures generally control equipment generated collateral radiation by using appropriate equipment housings/covers. The laser excitation device may produce very intense Ultra-Violet/Visible/Infrared radiation that can be hazardous. Laser operators can be exposed to hazardous levels of collateral radiation when protective housings are removed. Laser beam generated collateral radiation must be access for and control by the laser operators.

- *Infrared Radiation*

Infrared lasers produce an obvious source of this radiation, but many other items can generate infrared radiation in the laboratory as well (heating mantles, hot plates, thermal ovens, flash lamps, laser beam sample heating). Overexposure to infrared radiation can lead to skin burns and eye cataract. Regardless of the source for infrared radiation, laser operators must be aware of it and act appropriately to control exposure to it.

- *Ultra-Violet and Visible Radiation*

Besides the direct hazards of UV/visible laser beams, laser discharge tubes and pump lamps can generate hazardous levels of ultraviolet and visible radiation. Collateral ultraviolet radiation may injure both the eye and the skin if the exposure is of long enough duration. Lasers/laser systems should be operated only with protective housings in place.

- *Ionizing Radiation*

Some laser power supplies, may produce X-rays, of particular concern are those operating at potentials above 15 kV. The two main sources of these ionizing emissions are high voltage vacuum tubes and electric discharge lasers. In general, these X-rays are low energy and are shielded by the equipment housings. It is very important to leave interlocked power supply doors in place when the power supply is on, and not to defeat these interlocks. If your laser power supply or manual indicates that it can produce ionizing radiation, contact Radiation Specialist for more information on appropriate control measures.

- *Plasma Generated Radiation*

Interactions between a laser beam and a target may produce plasma radiation when materials are heated to very high temperature, resulting in the emission of intense broad spectrum light and potentially ionizing radiation. The emitted light may contain hazardous collateral UV radiation, which can cause conjunctivitis, photochemical damage to the retina or erythema (burns) to the skin. Laser operations that generate plasma radiation will require additional hazard controls.

- *Radio Frequency*

The generation of harmful levels of radio frequency (RF) emissions, many occur in laser components or as a result of laser beam interactions with target materials. RF shielding is required where the levels of RF radiation exceed safe levels, commercial lasers should have the appropriate controls to limit this hazard, and all shielding must be restored after servicing.

4. Fires

Class 4 lasers represent a fire hazard along with any highly focused laser beam, particularly class 3B lasers.

Specular reflections from class 4 lasers, and where laser light is concentrated to $10W/cm^2$ or greater can also be a fire hazard. These types of laser power can ignite or cause off gassing in combustible materials when the beam encounters them. Class 4 lasers and focused laser beams can ignite gaseous/dusty atmospheres; caution should be taken when using flammable solvents in the laser laboratory. The laser operator should be aware of their lasers beam path and check regularly to see that flammable materials are keep out of it. All 'stray' reflections must be blocked with non-combustible materials. Laser beam stops/blocks, table barriers, and room curtains that used must be made of compatible, noncombustible materials.

5. Explosions

Lasers/laser systems may be an explosion hazard, high-pressure arc lamps, filament lamps, and capacitors may explode violently if they fail during operation. Usually, these components are enclosed in housings that can contain the explosive forces produced, thus it is very important not to operate a laser without these protect housings in place. Laser targets, optical components and other elements of the optical path may disintegrate because of excessive heating or optical incompatibility. Consequently, the laser operator must take care and provide adequate shielding to sensitive components in the optical path. There are other potential explosion hazards in the laser laboratory: storage and use of flammable solvents/gases (both compressed and cryogenic) and implosion from cryogenic Dewar's and other evacuated chambers. Proper storage and control of these sources of explosions should reduce their potential hazard.

XII. Training

Operators of Class 3B and 4 lasers or laser systems must, prior to working with the laser(s), successfully complete Laser Safety training as offered by the EHS and obtain specific laser training from PI/ALU for the laser(s). Refresher training is required every two years. Record of the Laser training(s) must be documented and kept in Lab-Specific Safety Plan.

XIII. Medical Surveillance

No individual who will be using or operating a laser/laser system are required to obtain either a pre- or post-use eye exam by an ophthalmologist specific to laser use.

Following any suspected laser injury, the affected individual should seek medical assistance immediately or as soon as practical, when a suspected injury or adverse effect from a laser exposure occurs. In addition to the acute symptoms, consideration shall be given to the exposure wavelength, emission characteristics and exposure situation to ensure appropriate medical referral. Should eye contact with a direct or reflected beam occur, the affected individual should be transported to his ophthalmologist for medical treatment.

XIV. Laser Accidents/Emergency Procedures

A. Laser Accidents Reporting Requirements

In the event that an individual suspects a laser has injured them in either the eye or skin, the operators of the laser system shall be notified immediately so that the laser beam(s) can be terminated. Seek medical assistance by calling 911 or 919-530-6106. Notify the PI/ALU and EHS (ehs@nccu.edu; 919-530-7125; Health and Safety Reporting), as soon as is practical, if you suspect an injury from a laser beam. The PI shall report the incident to the NCCU Worker's Compensation Administrator at 919-530-7943 or callsbrook@nccu.edu and complete all necessary forms.

B. Accident/Emergency Procedures

In general, for any adverse incident the following should be done:

- Terminate laser operations, by pressing the EMERGENCY POWER OFF (EPO) button; it is located in the lab to shut down power to the lab.
- In the case of emergency, dial 911 or 919-530-6106 for assistance.
- Notify your supervisor or lab manager and EHS, as soon as practical

1. Spills (laser dyes, solvents, etc.)

Only trained and authorized individuals who are well aware of the hazards and decontamination methods for the particular chemicals involved shall clean small-scale hazardous material spills. The individual shall be fully prepared and equipped with proper PPE prior to attempting the cleanup. For large-scale spills, evacuate the building and call 911 or 919-530-6106.

2. Fire

- Activate fire alarm pull station in a building and alert others
- If possible shut off equipment, stabilize experiments if you can quickly do so and close the door
- Leave the building; DO NOT USE ELEVATORS
- Assist others in evacuating if possible
- Dial 911 or 919-530-6106 for assistance
- Assemble in a safe place away from danger
- Person with knowledge of the situation should meet with first responders
- Do not re-enter the building until cleared by first responders.

C. Major Causes of Laser Accidents

Approximately 70% of the laser incidents worldwide have resulted in permanent loss of vision. Following are the most common contributing factors that have led to laser eye and skin injuries.

- Eye exposure during alignment

- Misaligned optics and upwardly directed beams
- Out of position optics or modification of the beam path
- Adding or removing equipment into the beam path while laser is operating
- Not checking for stray reflections and not blocking stray reflections
- Reflections off surfaces
- Introduction of foreign materials (pages of loose paper, paper clips, falling items or objects)
- Equipment malfunction
- Improperly handling high-voltage
- Improper restoration of equipment following service
- Available laser eye protection not used or inappropriate eyewear for laser in use
- Eye or skin injury from a photochemical reaction
- Unanticipated eye/skin exposure during laser usage
- Lack of protection for non-beam hazards
- Inhalation of laser generated air contaminants and/or viewing laser generated plasma
- Fires resulting from the ignition of materials
- Intentional exposure of unprotected personnel
- Operators unfamiliar with laser equipment
- Failure to follow or have Standard Operating Procedures (SOPs)
- Lack of awareness of hazard from wavelength(s) in use
- Lack of communication

XV. Laser Safety Audits

The EHS will audit all Class 3B/4 laser laboratories and laser systems in use at NCCU. Initial audits are done so that the EHS can approve the use of a laser and laser laboratories. Annual audits are to be performed by PI/ALU and the EHS to verify inventory, completion of corrective actions, and use of lasers being in compliance with submitted SOPs. The EHS must approve all new lasers and laser systems before they can be used; this includes new setups for existing lasers. If a new SOP is required, then the setup must be audited prior to use. It is highly recommended that the EHS be notified of potential new PI/ALU, new lasers purchase, or new laser setups as soon as possible. With proper notification, the EHS and the PI/ALU can quickly address laser safety issues prior to the new laser(s) arriving.

A. Initial Audits (New laser)

Initial laser safety audits are performed when:

- A new P PI/ALU, regardless of whether they are registering a new laser or using an existing one
- A current PI/ALU who is registering a new laser
- A new or current PI/ALU who will be using an existing laser in a new setup/configuration
- Purchase of equipment containing an embedded laser of Class 3B or 4

Audits will verify that the following requirements are being met:

- The laser or laser system is FDA-CDRH certified
- SOP(s) are in place
- All necessary PPE and facility is in place and available
- General laboratory safety has been addressed

B. Annual Audits

All approved PI/ALU, lasers, and laser laboratories at NCCU must be audited at least once per year. The PI/ALU will coordinate their audit with the EHS annual laboratory inspection. Audits will verify that the following requirements are met:

- Inventory, both active and inactive, is current
- All new lasers have been registered
- Lasers have been properly disposed, transferred or otherwise removed from PI/ALU inventory
- Lasers are used as described in their SOPs
- SOPs have been read by all users
- SOPs are readily available, and followed
- Protective equipment is present, used, and in good condition
- Protective equipment may include, but is not limited to, any of the following:
    - Laser Eye Protection, lab coats, and other PPE
    - Beam stops, barriers
    - Table containment
    - Window covers
    - Laser curtains
    - Interlock systems
- A list of approved users is current and complete, unauthorized use is not permitted
- Security of laser(s)
- Training for all approved users is complete and current
- Laser facility door signage is present and current

- Illuminated laser warning sign is working and being used appropriately
- All Class 4 open beam lasers are connected to room interlock system

The PI/ALU must address any findings of deficiencies in their laser facility within 30 days of the safety audit. The response to the laser safety audits shall be sent to the EHS within 30 days of completion. The EHS will scheduled a follow-up visit with the PI/ALU as necessary. Appendix B is the Laser Safety Audit Checklist used by EHS during the inspection.

XVI. Appendix A Laser SOP Template

General
Principal Investigator: Click or tap here to enter text. Department: Click or tap here to enter text. Phone: Click or tap here to enter text. Email: Click or tap here to enter text.
Location
Building: Click or tap here to enter text. Room(s): Click or tap here to enter text. Phone: Click or tap here to enter text.
Equipment Information (can be found in the manufacturer's operation manual)
Manufacturer of Laser Head: Click or tap here to enter text. Laser Head Model: Click or tap here to enter text. Serial Number: Click or tap here to enter text. Manufacturer of Power Supply: Click or tap here to enter text. Laser Power Supply Model Number: Click or tap here to enter text. Serial Number: Click or tap here to enter text. NCCU EHS Laser Inventory Number: Click or tap here to enter text. Laser Type: Click or tap here to enter text. Beam Diameter (mm): Click or tap here to enter text. Beam Divergence (mrad): Click or tap here to enter text. Wavelength(s) (nm): Click or tap here to enter text. Class: Click or tap here to enter text. Output (J or W): Click or tap here to enter text. Pulse Duration (s): Click or tap here to enter text. Max Joules/pulse: Click or tap here to enter text. Repetition Rate (Hz): Click or tap here to enter text. Modifications to the Laser: Click or tap here to enter text.
Laser Application Summary
A brief description of the intended laser use, such as spectroscopy, chemical reaction work, wielding, etc. Click or tap here to enter text.
Beam Path(s)
Describe in full by either using a diagram or in clear and concise English the intended path of the laser beam from the laser head to its final target.

Click or tap here to enter text.			
Protective Equipment			
Describe in full ALL safety equipment that is associated with this laser and its intended use. Click or tap here to enter text.			
Laser Protective Eyewear			
Wear this eyewear: Click or tap here to enter text.			
Eyewear Manufacturer	Protection Wavelength(s)	Optical Density (OD)	Notes
Beam Hazards			
Describe in full ALL direct and indirect hazards that are associated with this laser beam and its intended use (beam height, reflections, UV radiation/blue light exposure, etc.). Click or tap here to enter text.			
Non-Beam Hazards			
Describe in full ALL direct and indirect hazards that are associated with this laser and its intended use (electrical and fire hazards, reflective surfaces, laser-generated air contaminants, hazardous gas exposure, chemical, cryogenic, etc.). Click or tap here to enter text.			
Turn ON/OFF Procedures			
Describe in full ALL steps necessary for the safe and proper, manner of starting and stopping this laser. Click or tap here to enter text.			
Alignment Procedures			
Describe in full ALL steps necessary for the safe and proper methods of aligning the internal and external beam for this laser. Click or tap here to enter text.			
Maintenance Procedures			
Describe in full ALL steps necessary for maintaining this laser in a safe and proper manner. Include also maintenance special training and what is NOT allowed. Click or tap here to enter text.			
Emergency Procedures			
Describe in full ALL procedures to be done in the event of an emergency (how to shut down the laser, how to respond to an alarm, etc.). Click or tap here to enter text.			

Authorized Users			
I have read this Safe Operating Procedure, understand its content, have been trained on implementing its contents and will utilize this procedure every time I use this laser system.			
Name (print)	**Signature**	**Date**	**PI Initial**
Initial Review			
The initial review of this SOP has been conducted and approved by the PI, EHS, and any other Department or College representative (if applicable) as indicated below.			
Name (print)	**Signature**	**Date**	**Affiliation**
Annual Reviews			
An annual review of this SOP has been conducted and approved by the PI and EHS (if applicable). They have found this SOP to still be correct and valid for the laser use that it herein describes.			
Name (print)	**Signature**	**Date**	**Affiliation**

XVII. Appendix B Laser Safety Audit Checklist

Date of Inspection: Click or tap here to enter text. Auditor Name: Click or tap here to enter text.

Principal Investigator: Click or tap here to enter text.

Building Name: Click or tap here to enter text. Room(s): Click or tap here to enter text.

Administrative	Yes	No	N/A	Comments/Follow-up Actions
Lasers are classified appropriately	☐	☐	☐	
Standard Operating Procedures are up-to-date, reviewed by users, and signed	☐	☐	☐	
Alignment procedures are available	☐	☐	☐	
Viewing cards are used for alignment	☐	☐	☐	
Lasers are included in inventory	☐	☐	☐	
Laser users completed appropriate trainings	☐	☐	☐	
Laser safety manual available, reviewed	☐	☐	☐	
Emergency contact list up-to-date and posted	☐	☐	☐	
Labeling and Posting	**Yes**	**No**	**N/A**	**Comments/Follow-up Actions**
Certification label present	☐	☐	☐	
Class designation and appropriate warning label present	☐	☐	☐	
Aperture label present	☐	☐	☐	
Appropriate warning/danger sign at entrance to laser area	☐	☐	☐	
Warning posted for invisible radiation	☐	☐	☐	
Control Measures	**Yes**	**No**	**N/A**	**Comments/Follow-up Actions**
Protective housing present and in a good condition	☐	☐	☐	
Beam attenuator present	☐	☐	☐	
Laser table below eye level	☐	☐	☐	

Approved: 10/25/2022
Approved by: K. Long-Witter, Director

Beam is enclosed as much as possible	☐	☐	☐	
Beam not directed toward doors or windows	☐	☐	☐	
Beams are terminated with fire-resistant beam stops	☐	☐	☐	
Surface minimize specular reflections	☐	☐	☐	
Controls are located so that the operator is not exposed to beam hazards	☐	☐	☐	
Personal Protective Equipment	**Yes**	**No**	**N/A**	**Comments/Follow-up Actions**
Proper PPE available - eyewear, lab coat	☐	☐	☐	
Eye protection is appropriate for wavelength	☐	☐	☐	
Eye protection has adequate OD	☐	☐	☐	
Warning/indicator lights can be seen through the protective filters	☐	☐	☐	
Proper skin protection available	☐	☐	☐	
Class 3B and 4 Lasers	**Yes**	**No**	**N/A**	**Comments/Follow-up Actions**
Interlocks on protective housing	☐	☐	☐	
Service access panel present	☐	☐	☐	
Limited access to spectators	☐	☐	☐	
Nominal hazard zone determined	☐	☐	☐	
Operators do not wear watches or reflective jewelry while laser is operating	☐	☐	☐	
Viewing portals present where MPE is exceeded	☐	☐	☐	
Class 4 Lasers	**Yes**	**No**	**N/A**	**Comments/Follow-up Actions**
Failsafe interlocks at entry to controlled area	☐	☐	☐	
Area restricted to authorized personnel	☐	☐	☐	
Laser may be fired remotely	☐	☐	☐	
If present, curtains are fire-resistant	☐	☐	☐	

Area designed to allow rapid emergency egress	☐	☐	☐	
Pulsed – interlocks designed to prevent firing of the laser by dumping the stored energy into dummy load	☐	☐	☐	
CW – interlocks designed to turn off power supply or interrupt the beam by means of shutters	☐	☐	☐	
Operators know not to wear ties around the laser	☐	☐	☐	
Non-Beam Hazards	**Yes**	**No**	**N/A**	**Comments/Follow-up Actions**
High voltage equipment appropriately grounded	☐	☐	☐	
High voltage equipment located away from wet surface or water sources	☐	☐	☐	
High voltage warning label in place	☐	☐	☐	
Compressed gases secured	☐	☐	☐	
Cryogens secured	☐	☐	☐	
Fume hood for dye mixing operational	☐	☐	☐	
SDS reviewed for dyes and other chemicals	☐	☐	☐	