United States Department Of Commerce National Institute of Standards and Technology **Safety, Health, and Environment Division** **HEALTH AND SAFETY INSTRUCTION**	Number 13 Issued: September 10, 2008 Supersedes: April 1996 Distribution: _____ Page 1 of 24

Subject: NIST LASER SAFETY PROGRAM

1 INTRODUCTION

Lasers pose unique hazards in the laboratory, and those hazards must be identified, understood, and controlled before using these systems. Lasers can operate across a broad spectrum, from the ultraviolet (UV) to the infrared (IR). Not all wavelengths present the same hazards. Additionally, hazards may vary depending on the specific nature of the lasers.

The most notable hazard is ocular. The lens and cornea of the human eye focus optical wavelengths between 400 nm and 1400 nm directly onto the retina. However, the human eye is only sensitive to wavelengths between 400 nm and 700 nm. The near-IR range (700 nm to 1400 nm) can present an increased hazard—in this range, light is still focused on the retina but is not visible. As a result, the blink reflex (or aversion response) is not present at these wavelengths. Retinal burns are the most common significant injuries that occur with lasers in the ocular wavelength range (400 nm to 1400 nm), although higher power lasers in this range can cause thermal burns to the skin as well.

Other IR lasers (1400 nm to 1 mm) emit light that is absorbed by the cornea and can result in thermal burns, both to the cornea and to the skin. This effect can be increased if the laser is used with magnifying optics. Chronic exposure to such IR sources has also been shown to contribute to cataract development. These wavelengths do not pose a retinal threat, as the light does not focus to the retina.

UV lasers (100 nm to 400 nm) pose additional hazards beyond that of thermal burns. Skin exposure to UV can cause erythema, similar to sun burns, and ocular exposure to UV lasers can cause photokeratitis (damage to the cornea, more commonly known as snow blindness or welder's flash). Exposure to certain UV wavelengths near 310 nm has been shown to cause cataracts to form in the lens of the eye. Chronic exposure to even low-power UV light, including diffuse reflections and scattered UV radiation, may pose long-term health hazards. Such hazards can include increased risk of skin cancers and cataracts.

Some higher-power laser radiation can present a significant burn hazard. Appropriate precautions should be taken to prevent skin exposure to hazardous beams. Hazardous beams include direct high-power or high-energy beams, focused beams, etc.

Finally, special attention must be given to the possibility of hazardous byproducts, also known as laser generated airborne contaminants (LGAC). LGAC may be aerosols, gases or vapors. For more information about LGAC hazards, see Appendix F of American National Standards Institute (ANSI) Z136.1—2007, American National Standard for the Safe Use of Lasers. (ANSI Z136.1).

2 PURPOSE

This health and safety instruction (HSI), based on ANSI Z136.1 (2007), defines a program for laboratory laser safety to assist and protect employees, associates, and visitors of the National Institute of Standards and Technology (NIST). The program as herein described must be implemented in all NIST Operating Units (OUs) and Divisions where laboratory lasers are operated. ("OU" and "Division" are used generically in this document, representing typical NIST organizational structure, and are intended to include organizationally similar entities used in some parts of NIST, such as "Center" and "Office.")

This document supersedes all previous documentation of NIST laser-safety program(s), and any OU or Division laser-safety programs shall be considered supplemental to this program. This program also addresses recommendations from the 2006-2007 assessment of NIST laser safety by the U.S. Army Center for Health Promotion and Preventative Medicine (CHPPM).

3 SCOPE

This program applies to the operation of all laboratory lasers at all NIST sites and joint institutes. ***Lasers used in construction at NIST must be treated separately and are not part of this program***.

4 POLICY

The NIST policy on laser safety requires that all lasers and laser systems are operated in a manner consistent with ANSI Z136.1 as well as other applicable regulations. These requirements for laser safety are complex and include identification of hazards, implementation of engineering and administrative controls, proper selection and use of personal protective equipment (PPE), and training. The goal of this program is to educate laser operators of potential laser hazards and to outline the steps that must be implemented so that injuries are avoided.

The primary objective of the NIST laser safety program is to ensure that no laser radiation in excess of the maximum permissible exposure (MPE, as defined in the ANSI standard) limit reaches the human eye or skin. Additionally, the program is designed to ensure that adequate protection against ancillary hazards is provided. These ancillary 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.

5 DEFINITIONS

Acronyms and important terms are defined at their first occurrence in the text of this document. A list of acronyms is shown in Appendix A.

6 LASER ACCIDENTS AND INJURIES

6.1 *It is up to the laser user to prevent laser accidents.*

It is the responsibility of the laser user to prevent laser accidents. The user accomplishes this by taking appropriate actions both before and during operation of the laser. Before operating the laser, the user must identify the hazards present and implement appropriate controls. During the operation of the laser, the user must follow correct operating procedures and proceed with alertness and care. The likelihood of a laser accident is greatest during the alignment process: 60% of laser accidents in research settings can be traced to alignment procedures. The overwhelming majority of laser-alignment accidents occur when the user is not wearing protective eyewear or is not taking steps to be protected from the possibility of stray reflections. Stress, fatigue, and complacency are the next greatest contributors to laser accidents.

6.2 What to Do in Case of a Suspected Injury

If a laser injury occurs or is suspected, NIST injury response/reporting policies must be followed (see Section 9), even if the injured individual considers the injury to be insignificant and not likely to interfere with his/her work. Many OUs have additional reporting requirements. The individual must seek medical attention immediately when an injury is suspected. If the suspected injury occurs during the normal business hours the individual must contact the Health Unit:

- In Boulder:
  Health Services Unit – (303) 497-3801
  Location: Skaggs Building, Room GB103
  7:30 AM to 4:30 PM, Monday through Friday
- In Gaithersburg:
  Health Unit – (301) 975-5131
  Location: Building 101, Room C33
  8:30 AM to 5:00 PM, Monday through Friday

The Health Unit will provide treatment or a referral to an appropriate medical professional.

In the event of an emergency and/or after hours, call the NIST-Boulder emergency numbers, 911 then extension 7777, or NIST-Gaithersburg emergency number, extension 2222. Unfortunately, most laser injuries go unreported and untreated for 24 to 48 hours. This is the critical time for injury treatment.

In addition, the injured individual must notify (or have someone notify) their Division Chief, Division Safety Representative (DSR), and Group Leader. Do not delay medical treatment if they are not available. The Division Chief and DSR have the responsibility to quickly inform the OU Director, Division Laser Safety Representative (DLSR) and the Safety, Health, and Environment Division (SHED) in Gaithersburg or the Office of Safety, Health, and Environment (OSHE) in Boulder, and the NIST (or site) Laser Safety Officer (LSO). While appropriate medical attention is the first concern, notifications must be made in a timely manner; NIST policy stipulates ***same-day reporting***. "Near misses" should also be

reported to the supervisor and the DSR, so that appropriate information can be shared, to prevent injury to others in similar circumstances.

6.3 Accident/Injury Investigation

All laser accidents or injuries must be investigated. It is important for injured or affected parties to realize that the purpose of reporting and investigating is to ensure that a thorough root-cause analysis is performed of all aspects of this laser-safety program, to determine all contributing factors to the incident and to prevent similar incidents in the future; it is NOT the intent to assign individual blame for the incident. All NIST rules for incident-investigation must be followed. It is very important to initiate the investigation as soon as possible after the incident, while details and recollections or witness accounts are still fresh. The investigation should be coordinated and overseen by the NIST (Boulder or Gaithersburg) LSO(s), and by other SHED or OSHE personnel, at the discretion of the SHED Chief. The DLSR should also participate in the investigation. Ideally, the investigative team should include one or more other members of the NIST Laser Safety Committee (LSC) from outside the injured party's Division and/or OU. A written report shall be issued and submitted to the Division Chief, as well as to SHED or OSHE to be shared with senior management and NIST staff as appropriate.

7 RESPONSIBILITIES

The technical-staff, technical-line-management, and collateral-duty responsibilities defined in this section pertain to those Divisions, Offices, Centers, and OUs that operate Class 3 and/or Class 4 laboratory lasers. These responsibilities as detailed below are required of all OUs, and the following sections allocate these responsibilities based on the typical NIST technical chain of command: OU – Division Chief – Group Leader – Project Leader – lab personnel. However, for those parts of NIST that do not have this structure, the specific responsibilities must be assigned and documented by the OU Director as appropriate.

7.1 Authorized User

Authorized Users are responsible for their own safety and the safety of those around them, including new users under observation (see Section 8.1.2). An Authorized User shall operate lasers in accordance with this laser-safety program at all times and ensure that all requirements (Section 8) of this program are met. If an Authorized User encounters a situation not covered by this program, or requires clarification of the policy, he/she is responsible for seeking guidance. In addition, all Authorized Users are expected to notify safety representatives and supervisors of any unsafe situations or practices, as well as missing or inoperative laser safety equipment. Authorized Users are required to notify the DLSR of all new or altered laser installations (Section 8.4).

7.2 Project Leader

Project Leaders shall ensure that laser installations meet laser-safety requirements, that adequate safety and protective equipment is supplied to staff, and that only Authorized Users are operating laser equipment.

7.3 Group Leader

Group Leaders are responsible for the safety of Group staff and associates. Group Leaders are responsible for ensuring that staff operate lasers according to this program and to take corrective action (including installation modifications or retraining, for example) when deficiencies are identified, to ensure compliance. Group Leaders are responsible for authorizing new users after necessary training and observation (by the Group Leader or designee) and maintaining records of authorization (See Section 8.1.2).

7.4 Division Chief

The Division Chief is responsible for the safety of all Division staff and associates. Therefore, the Division Chief is responsible for ensuring that all users operate lasers according to this program. The Division Chief seeks and obtains advice, guidance, and status reports from the DLSR, DSR, LSO(s), and others, and takes corrective action to ensure compliance with this program. The Division Chief appoints the DLSR and DSR and participates in the annual review of any Division-level laser-safety policy or supplemental programs.

The responsibilities defined for Project Leaders and Group Leaders assume that these individuals fully understand the hazards associated with lasers. If these individuals do not meet this requirement, the Division Chief shall delegate specific responsibilities to an appropriate individual or consult with the DLSR and/or LSO(s) for guidance. For example, a Group Leader may not have the laser safety expertise to properly authorize new users; in this case the Group Leader and/or Division Chief will consult with the DLSR or the LSO(s) to assess whether the proposed Authorized User has demonstrated an understanding of laser safety, both with respect to this program and to the specific laser systems under consideration. But, in all cases, the ultimate responsibility for authorization will remain with line management.

7.5 Operating Unit (OU) Director

The OU Director, or designee, is responsible for the safety of all OU staff and associates. With regard to laser safety, OU management is responsible for ensuring the implementation of this program in all Divisions that operate Class 3 and/or Class 4 laboratory lasers.

7.6 NIST Office of the Director

The NIST Deputy Director, acting on behalf of the NIST Director, as defined in the NIST Administrative Manual, is responsible for managerial oversight of all NIST safety programs

and policies and is responsible for the safety of all NIST staff and associates. With regard to laser safety, he or she is responsible for ensuring the implementation of this program in all OUs that operate Class 3 and/or Class 4 laboratory lasers.

7.7 Division Laser Safety Representative (DLSR)

Each Division, Office, or Center using laboratory lasers will appoint a person to oversee the laser-safety program. The DLSR:

- is responsible for guidance, oversight, and administration necessary to ensure Division compliance with this program;
- should be familiar with best practice in laser safety and is responsible for staying current with changes in regulations; this person should take advanced or supplemental laser-safety training and should fulfill additional periodic training requirements, as defined and developed jointly by the LSO(s) and LSC;
- leads the review of new or altered laser installations (Section 8.4);
- leads the annual laser-safety inspection (typically with the DSR as part of regularly scheduled safety inspections) and reports findings to the Division Chief;
- informs the LSO(s) of any changes in the Division's laser inventory;
- conducts an annual review of any Division-level laser-safety policy or supplemental programs;
- brings all potential laser-safety issues to the attention of appropriate parties and informs the Division Chief of any unresolved issues; and
- ensures that periodic training or information on training opportunities are made available to Division staff and associates.

The DLSR and the DSR may be the same person. If these positions are represented by more than one person, the efforts of these individuals should be coordinated to ensure overall safety and consistency of the relevant policies. In some cases, a DLSR can be appointed from outside a Division; for example, if a Division has a very small number of lasers, the DLSR role could be shared with another Division.

7.8 Division Safety Representative (DSR)

The DSR is responsible for guidance, oversight, and administration necessary to ensure Division compliance with general safety policies. With regard to this laser-safety program, the DSR is expected to provide this broader perspective to aid the DLSR in his/her role. The DSR:

- is responsible for interacting with safety-related organizations within NIST. In particular, the DSR will ensure that overall hazards (for example, electrical safety, chemical safety, and general safety concerns) are considered and documented;

- will assist, as appropriate or as merited by other potential hazards involved, with the activities of the DLSR; and
- is expected to bring all potential safety issues to the attention of appropriate parties and to inform the Division Chief of any unresolved issues.

7.9 NIST Laser Safety Committee (LSC)

The NIST LSC is a group of NIST laser-safety experts and administrators, including selected DLSRs, the NIST LSO(s), and others as appropriate. The LSC provides an opportunity for laser-safety personnel to share lessons learned, best practices, injury and near-miss information, training opportunities, etc., and to recommend potential improvements to this laser-safety program. The LSC shall develop, define, and communicate training procedures and opportunities for DLSRs, and it should assist DLSRs in identifying and communicating training opportunities for other personnel. The LSC also provides a pool of laser-safety experts who can take part in the investigation of laser injuries, accidents, and near misses and assist one another with laser inspections, calculations, and evaluations. The functions, membership, and procedures of the LSC shall be delineated in the LSC Charter.

7.10 NIST Laser Safety Officer (LSO)

The LSO position may be held by either one individual or by two individuals representing the two NIST campuses and shall be SHED and/or OSHE staff. The LSO(s)

- must be knowledgeable about lasers and laser safety, have documented LSO training, and be familiar with the relevant ANSI laser standard(s) but do not need to be technical laser experts;
- are responsible for the NIST level administration of this program;
- will serve on the NIST LSC;
- are responsible for initiating an annual review of this laser-safety program by the LSC;
- are responsible, with input from the DLSRs, for maintaining an inventory of Class 4, Class 3B, and invisible Class 3R lasers, coordinating baseline eye exams, providing laser safety training opportunities, and providing assistance to the DLSRs; and
- will be invited to participate in Division-level laser safety inspections.

7.11 NIST Safety, Health, and Environment Division (SHED)

SHED, represented in Boulder by OSHE, is responsible for the administration of all safety programs and policies at NIST. With regard to laser safety, SHED and OSHE are responsible for providing support and administration necessary for full implementation of this laser-safety program. SHED and OSHE are responsible for ensuring that this program meets all federal rules and regulations and that it remains updated and current. LSO(s) shall be SHED/OSHE staff.

8 REQUIREMENTS

All requirements of the NIST laser safety program are based on the ANSI Z136.1 standard.

8.1 Personnel Requirements

All NIST employees, associates, and visitors must fulfill NIST, as well as Division and/or OU, laser-safety training and authorization requirements before they can operate lasers or laser systems on their own. The types of requirements depend on the experience, education level of the potential user, and the type of equipment used.

8.1.1 Training

Staff and associates who work in Class 3 or Class 4 laser areas are required to be trained in laser safety. Supervisors will ensure that appropriate training is provided to laser users, DLSRs, and LSO(s). The level of training will depend on the degree of laser hazards. Training may include lectures, video- or software-based courses, hands-on training, and other training methods. At the supervisor's discretion, less experienced users may be required to take additional refresher training. Supervisors will consider the user's education level and cumulative laser experience when determining appropriate refresher training. Incidental staff (e.g., custodial and ancillary maintenance staff) having access to laser areas should be trained about the general nature of laser hazards and the meaning of laser-warning signs and lights, as appropriate or as part of general safety training received.

Each OU and/or Division must have laser-safety orientation/training procedures for all new employees, associates, and guests whose work assignment requires entry into any area in which laboratory lasers are used. Such orientation procedures are intended to familiarize new personnel with this laser-safety program as well as any supplemental OU and/or Division policies and procedures. For example, in the Optoelectronics Division (815), new personnel are required to read and demonstrate their understanding of this NIST laser-safety program to their Group Leader, including, at the option of the Group Leader, a written quiz.

Users of only low-power lasers (Section 8.2.1) are also encouraged to take laser-safety training.

All laser-safety training will be documented, with records retained by the Division and/or OU.

8.1.2 Authorization

Only Authorized Users may operate a Class 3B (or invisible 3R—see Section 8.2.3) or Class 4 laser. Personnel may be authorized upon compliance with the orientation/training requirements identified in Section 8.1.1. Line management may stipulate additional authorization requirements. New users with demonstrated laser experience and proficiency can be authorized prior to completing training requirements, provided that they sign a document certifying that an equivalent training has been successfully completed elsewhere, providing information regarding the source of the training and the laser systems for which training was received, AND stating that they will take and document appropriate NIST-

provided (or NIST-sanctioned) training at the earliest practical opportunity. Other methods of demonstrating existing proficiency may be possible at the discretion of the LSO(s) or LSC.

New users who are not yet Authorized Users may, as a part of their laser training, operate a Class 3B (or invisible 3R) or Class 4 laser, only under the direct supervision of an Authorized User who is present and attentive at all times.

After initial authorization of a new user, there may be an observation period (duration is at the discretion of the Group Leader), during which the ***new*** Authorized User can operate the laser(s) only under direct observation by an Authorized User designated by the Group Leader.

8.1.2.1 *Service Personnel*

Service personnel (e.g., field service technicians) are understood to be adequately trained for the systems for which they are providing service and therefore are exempt from NIST authorization requirements. The ANSI Z136.1 standard specifies that the LSO(s) shall confirm that service personnel have adequate education and safety training. Documentation of such, from service providers, will be retained by the LSO(s).

8.1.3 Medical Examination

ANSI Z136.1 recommends a pre-assignment eye examination for all personnel who will be working with Class 4 and Class 3B (including invisible Class 3R in the NIST laser-safety program—see Section 8.2.3) lasers. Such an examination can provide a record of the laser user's current eye-health status and establish a baseline against which any future ocular injury can be compared, but such exams do not directly contribute to the safe operation of lasers. NIST policy on such exams (whether to require, provide upon request, etc.) will be developed under the charter of the LSC and should follow the recommendations in Section 6 of ANSI Z136.1.

Additional eye examinations may be required for laser workers in the event of any accidental or suspected eye exposure to laser radiation. See Section 6 of ANSI Z136.1.

8.2 Specific Laser Laboratory Requirements

For a discussion of laser classes, see Appendix B. For classification questions, consult the DLSR, LSO(s), or ANSI Z136.1.

8.2.1 Low-Power Lasers (Class 1 and Class 2)

When used as designed, Class 1 and Class 2 lasers do not present a hazard to the user or those around them. The user should be aware of laser radiation hazards and should use these lasers safely. For Class 2, when personnel not familiar with the low-hazard nature of such lasers have routine access, a sign advising of the low-hazard nature of the operation is recommended (***Note***: yellow "Caution" sign – see Appendix C for an example).

8.2.2 Temporary Laser Areas

When an area not normally posted as a laser area contains temporarily accessible Class 3B (or invisible 3R—see Section 8.2.3) or Class 4 laser radiation (such as in the case of servicing of a device with an embedded laser), a sign, giving notice of the temporary hazard, shall be posted (***Note***: blue "Notice" sign – see Appendix C for an example, to be posted with an accompanying, properly annotated "Danger" sign – again, see Appendix C).

8.2.3 Class 3 and Class 4 Lasers and Laser Control Areas (LCAs)

Class 3R lasers and laser systems require a reduced set of controls. ANSI Z136.1 recommends, but does not require, that the controls detailed below be applied to Class 3R lasers. Class 3R laser radiation is not generally a hazard, except when directly viewed for longer than 0.25 s. This policy does not require implementation of the controls below for ***visible*** Class 3R lasers or laser systems. Because unintentional exposure is possible, however, this policy considers ***invisible Class 3R lasers to be equivalent to Class 3B***, meaning all controls below should be implemented for ***invisible*** Class 3R lasers or laser systems. Appendix B gives a more complete description of classifications.

Class 3B (and invisible 3R) and Class 4 lasers shall be operated only in appropriate laser-control areas (LCA). Operations must meet ANSI Z136.1 requirements or have equivalent operating standards reviewed by the DLSR. A LCA is defined as any area where Class 3B (or invisible 3R) or Class 4 laser radiation is accessible. The purpose of a LCA is to confine laser hazards to a well-defined space that is under the control of the authorized laser user, thereby preventing injury to those visiting and working in the laser area. Boundaries of a LCA are defined as points beyond which laser radiation above the Class 1 limit is not accessible. In many cases, the LCA may be a subspace of the more general laser laboratory (room). In such cases, the use of positive barriers (laser curtains, enclosures, fixed barriers, etc.) is an accepted method for creating the laser-control boundary. Temporary beam blocks, masks, and attenuators are generally not considered to be positive barriers.

Laser radiation levels in excess of the Class 1 limit must not pass the boundaries of the LCA. If windows, doorways, open portals, and other openings are part of the laser-control-area boundary, they must be covered or shielded to preclude the escape of hazardous laser light. Special rules apply for applications outside the scope of ANSI Z136.1 (such as outdoor use and other LCAs that do not provide complete containment). Consult the DLSR or LSO(s) for appropriate standards to use in such cases.

Special cases exist in which there is no routine or frequent access to hazardous levels of laser radiation. One such case is an ***embedded*** laser, where the laser is permanently or semi-permanently built into another instrument or apparatus, with no routine (other than service) accessibility. Such a laser has no routinely accessible emission and presents a hazard only when the embedding apparatus or housing is opened, for maintenance/servicing for example. Consequently, no controls are needed except when the laser emission is temporarily accessible (see Section 8.2.2 and Appendix D). Such devices must have interlocks to ensure that when the device is open the laser is turned off; only the qualified service technician or Authorized User may operate the laser in the open configuration (interlock defeated) with adequate safeguards. Other similar examples, of infrequent accessibility (alignment,

adjustment, etc.), are cases where the laser radiation is completely enclosed (e.g., enclosure built around experiment) or confined in optical fiber (see Section 8.3.1)

LCA requirements (posting, eye protection, exterior containment, and laser-warning lights) are somewhat complex. A Division and/or OU may optionally develop simpler supplemental guidelines, to aid users in understanding how these requirements apply to various configurations of LCAs (as well as various laser classifications). An example is shown in Appendix D. The use of such a chart, or similar simplified documentation, is for guidance only and should be used to supplement, and not as a substitute for, a thorough understanding of the requirements in the sections below.

8.2.3.1 *Standard Operating Procedures (SOPs)*

ANSI Z136.1 requires that each Class 3B (including invisible 3R in the NIST program) and Class 4 laser activity or operation has a written standard operating procedure (SOP), including details of the laser(s) use and alignment. Appendix E provides a general SOP for Class 3B (and invisible 3R) and Class 4 laser use, which can be adapted, with specific modifications, for typical laser applications. This can be superseded by the operating procedure provided by the commercial-laser manufacturer, if the laser is used as designed. For lasers with unique requirements or special safety concerns, a customized SOP is required. The laser-related SOP may be part of a broader SOP for more complex operations in a given lab. The SOP should describe what the particular hazards are, where practical, to help give context and perspective to listed procedures. Contact the DLSR or LSO(s) for guidance. NIST, OU, and/or Division requirements for hazard review may impose additional SOP requirements; laser-related SOP development should be coordinated with other hazard-review processes, where applicable.

8.3 Laser Control Area Requirements

The following sections apply to all designated LCAs.

8.3.1 Beam Control

Within the LCA, every reasonable effort shall be made to confine all laser beams to the optical table or to within the experimental boundaries at all times during routine operation. To establish and maintain this control, it is essential to be aware of all beams that can be classified as greater than Class 1 (including diffuse and specular reflections) and to terminate them with beam stops at the end of their useful paths. Beam stops provide protection from misaligned beams and should be placed in all appropriate and practical locations. When a beam traverses to other tables or across aisles, the beam must be enclosed, or the access to the aisle must be blocked, to prevent exposure to the beam. Secondary reflections and missteered beams (e.g., beamsplitters, uncoated lenses, and misaligned periscopes) are common sources for unanticipated specular reflections. Appropriate beam-control measures must be taken to account for all beam paths. As a matter of standard good practice, lab layout should be designed to minimize the number of accessible laser beams at typical eye levels.

Optical fiber is an excellent method for beam control of Class 3 (or lower power) lasers, as well as Class 4 lasers with up to 1 W of power. When using a fiber-confined laser, however, a hazard may still exist for a small region at the output of the fiber (from the fiber end, to a distance at which the beam expands to a safe power density). Eye hazards are increased when using direct optical viewing aids with laser-coupled fiber. For Class 4 lasers over 1 W, fiber may not be a dependable method for beam control, due to the considerable potential for fiber damage at such powers. The fiber-end hazard becomes appreciably larger for such cases, as well. The DLSR will be consulted for guidance if fiber is going to be used with powers in excess of 1 W.

8.3.2 Eye Protection

The Authorized User is responsible for ensuring that appropriate laser-protective eyewear is worn by ***all*** personnel within the LCA, whenever Class 3B (or invisible 3R) or Class 4 laser radiation is accessible. The eye protection must have the appropriate optical density based on the wavelengths of the beams encountered, the beam intensity, and the possible exposure conditions. The calculation of minimum required OD can be complex and requires a thorough understanding of ANSI Z136.1; users should consult the DLSR, who in turn can consult with the LSO(s) or other LSC members, for assistance with OD calculations. Commercial software for OD calculation is available, but the use of such software does not replace the need for thorough understanding of ANSI Z136.1. OD calculation software should be evaluated by the LSO(s) and/or the LSC for appropriateness and accuracy.

If multiple lasers are to be used simultaneously, appropriate broadband protective eyewear, covering all hazardous emitted wavelengths, is required. If appropriate eyewear is not available, lasers will not be used simultaneously unless physical barriers (curtains, room dividers, beam tubes, enclosures, etc.) are in place to confine the emission and to control exposure. Of special concern is the rapidly emerging technology of broadly tunable laser sources such as “frequency combs” and supercontinuum lasers. Such lasers complicate the eyewear selection process; for such cases beam control or other engineering controls become increasingly important.

Laser-protective eyewear is not usually required for Class 2 or visible Class 3R lasers or laser systems, except in rare cases where intentional direct viewing would be required.

8.3.3 Inspections

Each laboratory must undergo a laser-safety inspection at least once per year. These may occur in coordination with regular safety inspections. The DLSR (with possible assistance from the LSO(s) or other members of the LSC) is responsible for performing this inspection and, in possible coordination with the DSR, must submit a written report, describing findings and required corrective actions, to the Division Chief, with a copy to the LSO(s). All major safety deficiencies will be corrected before laser operation can resume; for cases where permanent correction will take time to implement, temporary protective features will be implemented (i.e., engineering and administrative controls, additional training, etc.) to protect facilities, operators, and associated personnel.

Additional reviews are required for new or altered installations (see Section 8.4).

8.3.4 Laser Warning Lights

A red light must be provided at the entrance to the LCA or laser laboratory and shall operate when the laser is emitting radiation. Furthermore, to avoid diluting the effectiveness of the warning that such a light provides, the red light should not operate when the laser is not emitting. In the event of a failure of the warning light, prompt action shall be taken to ensure timely maintenance/repair. If operation of the warning light cannot be immediately restored, alternate measures (e.g., dated, specific signage), developed in consultation with the DLSR and/or DSR, can be used for no more than five working days.

Although ANSI Z136.1 allows flexibility in types of warning lights, the lights used across either NIST campus, or across NIST as a whole, must be uniform and unambiguous in the warning provided to all personnel (including incidental personnel) who might seek entrance to a laboratory. Any alternative to the standard wall mounted red-light fixture predominantly used throughout NIST shall be reviewed and approved, in writing, by the DLSR and LSO(s) and must provide warning that is clear and equivalent to the standard mounted red lights.

8.3.5 Posting

LCAs must be posted with appropriate laser-warning signs (that is, per ANSI Z136.1) that indicate the nature of the hazard(s). See Appendix C for examples of required signage. In practice, signs and warning lights (see 8.3.4) are often placed together at room entrances, even if the LCAs comprise smaller subspaces within the rooms.

8.3.6 Room Access

When the laser is operating, access to the LCA by spectators or visitors must be limited and controlled by the Authorized User. Occasional visitors who require access into a LCA must be accompanied by an Authorized User. When a laser-warning light is illuminated outside of a laboratory, no entry into the room is permitted, even if the LCA is typically a subspace of the room, without explicit authorization by an Authorized User who is familiar with the specific laser usage in the room at that time.

8.3.7 Substitution of Alternate Control Measures

As in the ANSI Z136.1 Laser Standard, the engineering-control measures required for Class 3B (and invisible 3R) and Class 4 lasers or laser systems may be replaced by alternate engineering controls, administrative controls, or PPE that provide equivalent protection. The Authorized User will seek approval for alternate control measures through a review process with their Project Leader, the Group Leader, and the DLSR and LSO(s). The purpose of this review process is to ensure that alternate control measures satisfy all of the requirements outlined in this section. Approved alternate controls will be documented by the LSO(s).

8.4 New or Altered Laser Installations

The creation of a new LCA, arising from the introduction of a laser, is considered a new laser installation. The DLSR must be informed of any new laser installations, including details (laser type and classification, laser control area, etc.) for review and documentation by the DLSR. The purpose of this review is to ensure that all requirements in Section 8 are met, including the determination of whether existing training and authorization procedures are adequate for the hazards introduced by the new installation. If a new laboratory is being set up, or if there are significant and/or non-routine laser hazards involved, a more formal Division-level hazard review (including the DSR and appropriate line management) may be required. If there is question as to whether the new installation meets criteria for Division-level hazard review, the DLSR will consult with the DSR and the Division Chief before proceeding. Additionally, all NIST and/or OU requirements for hazard review must be met.

A laser installation is altered when a new hazard is introduced into an existing laser installation. In this case, the Authorized User shall follow the same review process as for a new laser installation. Additionally, any written Standard Operating Procedure (SOP) for the laboratory containing the new or altered laser installation may be required to be amended, especially if a new non-laser hazard is being introduced. Section 8.2.3.1 describes SOP requirements for lasers.

Moving portable lasers among laboratories (with LCAs defined and accurate signage) is not considered an alteration of the laser installation, provided that the required procedures are followed the ***first*** time a new hazard is introduced. In all cases, the Authorized User will ensure that the laser-warning signs posted outside the laboratory are up-to-date (see Appendix C.).

8.5 Other Requirements

In addition to laser-warning signs, non-beam hazards should be posted, as appropriate, per relevant safety standards (see Section 9), to provide a general laboratory hazard assessment. Exposure to incoherent ultraviolet (UV), radio-frequency, and microwave radiation, as well as magnetic fields, must be kept as low as reasonably achievable. Levels are never to be greater than is permissible under applicable standards.

8.5.1 Electrical Safety Requirements

Laser systems may operate at dangerous levels of voltage and current. In many cases, the electrical hazard can be greater than the optical hazard. Under such circumstances, users will adhere to electrical-safety, as well as lockout/tagout, guidelines, as referenced in Section 9.

8.5.2 Chemical Safety Requirements

Gas, vapor, and dye laser systems use chemicals that may be hazardous. Additionally, high-power lasers can produce vaporized products, e.g., laser generated air contaminants (LGAC) that may be hazardous. (See Appendix F, ANSI Z136.1 for a description of non-beam hazards associated with laser systems.) Appropriate labels and signs must be in place, and

proper chemical-safety techniques, including the use of appropriate personal protective equipment, are required; see Section 9 for policies regarding gases and chemical hygiene and labeling.

8.5.3 Fire Safety Requirements

Class 3B and Class 4 lasers pose a significant fire risk. Selection of appropriate materials for beam stops, barriers, and/or curtains is crucial. Care must be taken to keep combustible and flammable materials away from the beam path. See Section 9.

9 REFERENCES, STANDARDS, AND RELATED REGULATIONS

The NIST Safety Operational System is defined in Chapter 12 of the NIST Administrative Manual, available at:

http://www-i.nist.gov/admin/mo/adman/1201.htm

NIST has formal policies regarding the response to and the reporting of injuries. Summaries of these policies are available at:

http://www-i.nist.gov/director/safety/reporting.htm

The most pertinent laser safety standard is:

American National Standards Institute (ANSI) Z136.1, 2007, *American National Standard for the Safe Use of Lasers* (or later revision). [LSO(s) shall have current versions of the ANSI standard, which is also currently available from the NIST libraries; DLSRs, depending on the extent of laser operations within Divisions, should also typically have a copy.]

For non-beam hazards see OSHA 29 CFR 1910.

The NIST Safety Office maintains the NIST Laboratory Safety Manual as well as a set of Health and Safety Instructions (HSIs), which cover a wide range of safety-related issues (*http://www-i.nist.gov/admin/ohsd/hsinstrc.htm*). HSIs (as well as other related policies and regulations) that are pertinent to typical laser usage are referenced below.

NIST Laboratory Safety Manual

http://www-i.nist.gov/admin/ohsd/hslsmcon.htm

Compliance with Occupational Safety, Health, and Environmental Standards and Regulations

NIST HSI #1 – Compliance with Occupational Safety/Health Standards and Environmental Regulations (January 1998): *http://www-i.nist.gov/admin/ohsd/hshsi1h.htm*

Electrical Safety

National Fire Protection Association (NFPA) NFPA 70E: Standard for Electrical Safety in the Workplace (2004, or later revision). (available from SHED/OSHE)

NIST Electronics and Electrical Engineering Laboratory Electrical Safety Rules for Moderate & High Voltages (Dec. 1998): *http://www-i.eeel.nist.gov/safety/safety_rules_mod_hi_voltages.htm*

[reserved for NIST Plant Division Instruction for electrical work permitting]

Fire Safety

NFPA 101: Life Safety Code (2006, or later revision). (available from SHED/OSHE)

NFPA 45: Standard on Fire Protection for Laboratories Using Chemicals (2004, or later revision). (available from SHED/OSHE)

Gases

NIST HSI#5 Compressed Gas Cylinders (July 1999): *http://www-i.nist.gov/admin/ohsd/hshsi5h.htm*

Chemical Hygiene

NIST HSI #20 – Occupational Exposure to Hazardous Chemicals in Laboratories: Chemical Hygiene Plan (January 1991): *http://www-i.nist.gov/admin/ohsd/hshsi20h.htm*

Lockout/Tagout

NIST HSI #21 – Control of Hazardous Energy (Lockout/Tagout) (June 1994): *http://www-i.nist.gov/admin/ohsd/hshsi21h.htm*

10 APPENDICES

10.1 Appendix A: Acronyms Used in this Document

Acronym	Definition
ANSI	American National Standards Institute
CHPPM	(US Army) Center for Health Promotion and Preventative Medicine
CW	Continuous wave
DLSR	Division Laser Safety Representative
DSR	Division Safety Representative
HSI	Health and Safety Instruction
IR	Infrared
LCA	Laser control area
LGAC	Laser generated airborne contaminants
LSC	NIST Laser Safety Committee
LSO	Laser Safety Officer
MPE	Maximum permissible exposure
NIST	National Institute of Standards and Technology
OD	Optical density
OSHE	Office of Safety Health and Environment (Boulder)
OU	Operating Unit
PPE	Personal protective equipment
SHED	Safety Health and Environment Division (Gaithersburg)
SOP	Standard operating procedure
UV	Ultraviolet

10.2 Appendix B: Classes of Lasers

To provide a basis for laser safety requirements, all lasers and laser systems and/or devices in the U.S. are classified into one of several classes by the manufacturer. Corresponding labels are affixed to the laser or laser system. Understanding the laser classification is a fundamental prerequisite for any discussion of laser safety.

The following sections describe the hazard classification scheme adopted by the ANSI Z136 committee in 2007. The reader must realize that lasers or laser systems purchased prior to 2007 may have labels that correspond to the previous ANSI Z136 classification scheme (including, in some cases, the use of Roman numerals for laser classification). Please consult the DLSR if you have any questions about classification or labeling.

Class 1 Lasers

Laser products that do not emit harmful levels of radiation and are, therefore, exempt from control measures or forms of surveillance. As a matter of good practice, unnecessary exposure to Class 1 laser light should be avoided.

Class 1M Lasers

A subcategory of Class 1 lasers is Class 1M. This classification describes laser products that are safe for the unaided eye with no added optical elements, and are safe under every reasonably foreseeable viewing condition without optical aids. Labeling would state, "Do not view directly with hand-held magnifiers or microscopes" for a diverging beam, and "Do not view directly with binoculars or telescope" for collimated beams. These products are exempt from any control measures other than to prevent potentially hazardous optically-aided viewing and are exempt from other forms of surveillance.

Class 2 Lasers

Laser products that emit in the visible portion of the spectrum (400 to 700 nm) and for which eye protection is normally afforded by its natural aversion response, i.e., the human eye will blink within an exposure time T less than 0.25 s when exposed to Class 2 laser light. This blink reflex provides adequate protection. It is possible, however, to overcome the blink reflex and to stare into a Class 2 laser long enough to cause damage to the eye. Class 2 lasers have power levels less than 1 mW. Class 2 lasers are commonly used in alignment applications. These products are exempt from any control requirements under normal operating conditions. As a matter of good practice, doors should be closed, and appropriate warnings may be posted.

Class 2M Lasers

A subcategory of Class 2 lasers is Class 2M. This classification describes visible lasers that are safe to view by the unaided eye for 0.25 s. Like Class 1M, they are unsafe under some viewing conditions with optical aids. These products are exempt from any control measures other than to prevent potentially hazardous optically-aided viewing and are exempt from other forms of surveillance.

Class 3 Lasers

Class 3 lasers and laser systems may be hazardous under direct and specular reflection viewing conditions, but are normally not a diffuse reflection or fire hazard. The DLSR can provide guidance or assistance for such classifications and appropriate control measures. Refer to Section 8.3 for operating requirements.

There are two subclasses within this classification:

- Class 3R laser systems are potentially hazardous under some direct and specular reflection viewing conditions if the eye is appropriately focused and stable, but the probability of an actual injury is small. Class 3R laser systems have power levels of nominally 1 – 5 mW. This range is strictly true only for visible wavelengths (400 to 700 nm). For other wavelengths, the ANSI Z136.1 must be consulted. For those familiar with older classification schemes, Class 3R is roughly equivalent to "Class 3A" in previous versions of ANSI Z136.1. The most notable exception is for divergent-beam laser diodes and fiber-coupled lasers. Many such devices that were previously classified as 3A can be Class 2M, or even Class 1M, in the new classifications.
- Class 3B (including invisible 3R in this NIST program) lasers and laser systems may be hazardous under direct and specular reflection viewing conditions. In general, they do not pose a significant skin hazard except for higher powered lasers operating at certain wavelength regions. Class 3B lasers have power levels nominally greater than 5 mW and less than 0.5 W under cw operation. Under pulsed operation, Class 3B laser systems also cannot produce energy greater than 0.125 J within an exposure time T less than 0.25 s, i.e., the eye's normal blink reflex, or greater than 30 mJ/pulse within the laser wavelength region from 400 to 700 nm. For other wavelengths, ANSI Z136.1 must be consulted.

Class 4 Lasers

Class 4 lasers include all lasers that pose a hazard to the eye or skin from the direct beam and may pose a diffuse reflection or fire hazard. Class 4 laser systems may also produce LGAC and/or hazardous plasma radiation. These systems produce optical radiation at power and/or energy levels in excess of systems designated as Class 3B or below. All of the control measures in this document must be implemented.

10.3 Appendix C: Examples of Laser-Warning Signs

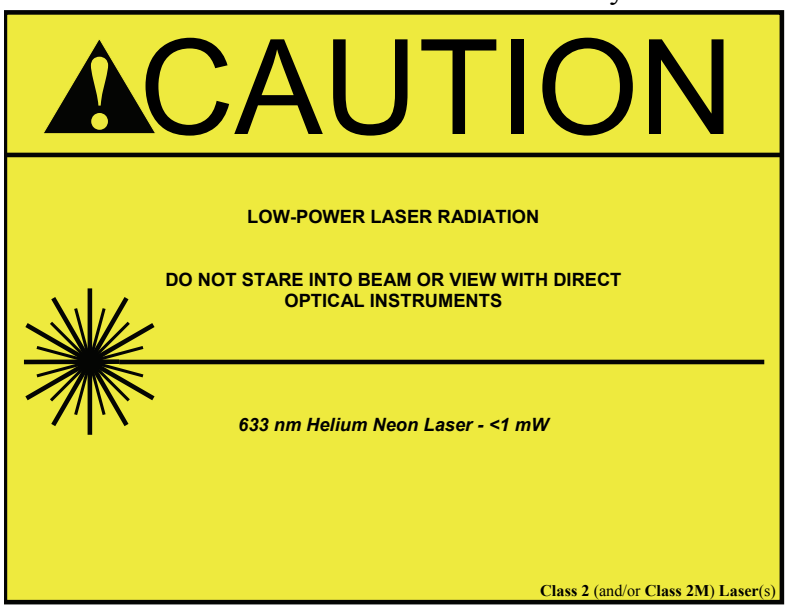
A laser-warning sign shall be posted outside of each laboratory containing a Class 3B (or invisible 3R) or Class 4 laser or laser system. A laser-warning sign optionally should be posted outside of each laboratory containing a visible Class 3R laser or laser system. There is no requirement for Class 1 or 2 laser systems. The type, wavelength, and power (or pulse energy, duration, and repetition rate) of each laser must be listed. If a laboratory contains lasers or laser systems that are designated by different classifications, the sign that meets requirements for the highest classification must be used to list all of the lasers. For example, if a laboratory contains both Class 2 and 4 lasers, the Class 4 sign shall be used. Examples of the required signs are shown below (*intended nominal size: 11" × 8.5"*). Templates for common laser-warning signs exist on the NIST internal safety website.

Danger

The signal word "Danger" shall be used on all signs and labels for all Class 3R (optional, for visible 3R), Class 3B, and Class 4 lasers and lasers systems. The top banner (backing the word "Danger"), the "!," and the "laser-starburst" pattern shall be red. The Class is identified in the right bottom corner. Laser-specific information is contained in the lower portion and appropriate hazard information in the upper portion. If protective eyewear is required (invisible Class 3R, Class 3B, and Class 4), the optical density (OD) of the protective eyewear and wavelength shall be shown on the sign. Users can consult with the DLSR if they need assistance determining the appropriate OD of the protective eyewear for their laser system. ANSI Z136.1 gives specific guidance on the hazard wording, with subtle differences between Class 3R, Class 3B, and Class 4. One should carefully study the ANSI standard and consult the DLSR, if he/she wishes to deviate appreciably from the hazard wording in the templates. A Class 4 example is shown below.

Caution

The signal word “Caution” indicates a potentially hazardous situation which may result in minor or moderate injury. The “Caution” sign shall optionally be used with all signs and labels associated with Class 2 and Class 2M lasers and laser systems.



Notice

When an area not normally posted as a laser area contains temporary accessible Class 3B (or invisible 3R) or Class 4 laser radiation (such as in the case of servicing of a device with an embedded laser), a sign, giving notice of the temporary hazard, shall be posted, as shown in the following example. The word “Notice” with a blue background is used for this sign. The “notice” sign must accompany a “danger” sign with specific details of the temporary hazard.

10.4 Appendix D: Example Guidance for Laser Control Area (LCA) Requirements

This chart was developed by the Optoelectronics Division (815) to give at-a-glance guidance for implementation of the LCA requirements of this laser-safety program in a typical laser laboratory. It is to be used as a supplement to, not a substitute for, a thorough understanding of the requirements.

Category	Condition	Laser-Protective Eyewear?	Laser-Warning Light On?	Sign Type	Door(s) Closed?
A	ACCESSIBLE Classes 3B† and 4	Y	Y	"Danger"	Y
The limits of the room are the limits of the LCA. All spaces within the room are considered inside the LCA, and exposure in excess of the Class 1 limit is ***possible*** anywhere in the room. Eyewear is required, the laser-warning light must be on, and all doors must be closed.					
B	CONTROLLED Free-Space Classes 3B† and 4	Outside LCA: **N** Inside LCA: **Y**	Y	"Danger"	Y
The laser light within the room is confined to a smaller LCA within the room (with boundaries set by laser curtains or barriers, for example). During normal operation, no light beyond the Class 1 limit (including specular and diffuse reflections) can pass beyond the boundaries of the LCA. **Category *A* hazards exist within the LCA, and personnel within the LCA must wear appropriate laser-protective eyewear**. During non-routine use (alignment, installation, maintenance, etc.), if it is possible for laser radiation in excess of the Class 1 limit to be present beyond the normal LCA, then the room reverts to Category ***A*** and all requirements of Category ***A*** must be met.					
C	CONTROLLED Fiber-confined Classes 3B† and 4*	3B: N 4 (≤ 1 W): N 4 (> 1 W): Y*	Y	"Danger"	3B: Recommended 4 (≤ 1 W): Recommended 4 (> 1 W): Y*
Optical-fiber confinement of laser radiation can often* be considered a special case of an LCA. Fiber-based systems are considered controlled when all fibers are terminated and there is no accessible free-space laser light in excess of the Class 1 limit. This circumstance ***can*** allow for open lab door(s), even when the laser is energized and the laser-warning light is on (such practice is not necessarily endorsed or recommended by this laser-safety program, however, and **door(s) must be closed at any times that the room is unoccupied while the fiber system is energized**). When fibers are disconnected, while the fiber system is energized, or when part of the light path traverses free space, the laser light is no longer controlled within the fiber system. In such cases, the area reverts to ***Category A*** (or Category ***B***, if an appropriate alternate LCA exists). *For Class 4 lasers with power exceeding 1 W, fiber cannot generally be considered a dependable method for beam control, due to the considerable potential for fiber damage by such powers. The DLSR should be consulted for guidance if fiber is going to be used with powers in excess of 1 W.					
D	Class 3R†	***See section 8.2.3 for guidance on applying controls for Class 3R***			
E	Class 2	N	N/A	"Caution" (recommended)	Recommended
F	EMBEDDED and Class 1	N	N/A	N/A	N/A
Embedded lasers are lasers that are incorporated into systems that are sealed in such a way that laser radiation is totally inaccessible during normal operation. Interlocks and permanent protective housings are examples of elements in an embedded system. In the event that there is access to Class 3B (or invisible 3R) or Class 4 laser radiation from such a device (during servicing, for example), temporary signage must be posted (see Appendix C), door(s) must be closed, and appropriate laser-protective eyewear must be worn. Class 1 lasers are not considered laser hazards and, as such, do not require additional safety regulations. Class 1M requires specific labeling that states, "Do not view directly with hand-held magnifiers or microscopes" for a diverging beam, and "Do not view directly with binoculars or telescope" for collimated beams.					

†Class 3B requirements also apply to ***invisible*** Class 3R lasers, in accordance with the NIST laser safety program.

10.5 Appendix E: General Standard Operating Procedure for Typical Standard Laser Usage and Applications

All class 3B (and invisible 3R) and class 4 laser systems are required to have standard operating procedures (SOPs) established for turn on, alignment, use, and shut-down. For all commercial laser systems, the manufacturer's SOP/Manual will be followed. For modified or customized lasers and laser systems, the following basic safety protocols related to laser operation shall be followed. For lasers with unique requirements or special safety concerns, a customized, specific, detailed SOP is required.

Start-up.

1. Ensure that all personnel that will be working in the laser control area (LCA) have the appropriate laser protective eyewear for the wavelengths and power levels that can be present.
2. Confirm that the laser warning light is on before energizing the laser.
3. Ensure that all necessary engineering controls are in place, e.g. cavity-shutter, beam stops, shrouds, etc.
4. If water cooling is used, open water valves and visually check for coolant leaks
5. Bring power up to minimal level if possible.

Experimental beam alignment.

1. Confirm minimal power level setting of laser. Where possible, use beam attenuators, accounting for and controlling all reflection, to get laser power to the lowest usable alignment power. If coaxial lasers are available for alignment, ensure that the primary laser is safely shuttered before working with the secondary alignment laser.
2. If eyewear is needed during operation of the laser at the minimal power setting, a secondary method of safely viewing the beam should be employed, e.g. IR viewer, IR card, UV card, etc.
3. Confirm that all secondary specular reflections are accounted for, and blocked if necessary before increasing power.

Laser service and alignment.

1. Follow all practices for start-up and experimental beam alignment.
2. If laser wavelengths and/or power levels are in excess or are different from the posted hazards on the laser warning sign, a temporary notice sign must be placed outside of the LCA to warn of the increased hazard.
3. If alignment requires temporary removal of the laser housing, ensure that there is no exposure to electrical hazards; if exposure exists, follow the electrical safety procedures in the NIST laser-safety program.

Use.

1. All users within the LCA shall wear the appropriate laser protective eyewear. If wavelength or power changes are part of regular use, ensure that the laser protective eyewear for anyone within the LCA is designed to accommodate the different wavelengths and/or power levels.
2. If the beam is to be steered or redirected during use, ensure that all primary and secondary specular reflections are blocked or shielded, and cover the extent of the motion of the beam.
3. If optics will be inserted or removed from the beam path during operation and use, ensure that:
    a. The beam is shuttered or blocked upstream of the optic during the actual movement of the optic, or
    b. All unused primary and secondary specular reflections coming from the moving optic are blocked or shielded throughout the path of the optics' movement.

Shut-down

1. Block the beam at furthest point upstream possible.
2. Reduce power to minimal levels if possible.
3. De-energize the laser or shutter the laser cavity if the power for the laser must remain on.
4. Ensure that the shutter is secure and/or the laser is powered down.
5. Close coolant valves, if chilled water is used; visually check for leaks.
6. Turn off the laser warning light.