KING ABDULLAH UNIVERSITY OF SCIENCE AND TECHNOLOGY

LASER SAFETY MANUAL

May 2023

Health, Safety and Environmental Department

Document History & Revision Status

Date	Revision	Prepared by	Description of change
Sep. 2014	00	C. Davey	Initial Document
Oct. 2018	01	K. Al-Qarni	Review of the content and consolidate the Permit/Registration of lasers
Sep. 2020	02	D. Darios	Review the whole laser registration process (including lab design, transfer, sale, etc.), add laser user registration via BioRAFT and review the laser injury procedure.
Aug. 2022	02.1	R. Gorchakov	Links update
May 2023	03	D. Darios	Review the registration to match what is currently done. Add a section regarding Medical Surveillance and amend the section regarding Emergency Procedure to include the link to Occ Health website.

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1. INTRODUCTION

This manual outlines the Laser Safety Program for KAUST which has been developed to provide guidance to faculty, staff, students and visitors for the safe use of lasers and laser systems.

The primary purpose of the KAUST 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. The program also aims to ensure adequate protection against non-beam hazards that can be associated with lasers. Non-beam hazards include, but are not limited to, electrical shock, explosion, fire hazards, as well as personal exposure to harmful chemical, biological hazards or collateral non-laser radiation (NLR).

To achieve these objectives, KAUST requires that all Class 3B and Class 4 lasers and lower class systems containing embedded Class 3B and Class 4 lasers (also called embedded lasers such as a confocal microscope), be operated in accordance with the safety guidelines established by the American National Standard Institute (ANSI) standard Z136.1-2014, *American National Standard for the Safe Use of Lasers* and standard Z136.8 – 2012, *American National Standard for the Safe Use of Lasers in Research, Development, or Testing.* This Laser Safety Program applies to all KAUST research spaces, including mobile and temporary locations. The objectives of the Laser Safety Program are to:

- Identify potential hazards to health and safety associated with lasers, laser systems and laser operations and to prescribe suitable means for the evaluation and control of these hazards;
- Investigate all laser incidents and introduce immediate corrective action to prevent reoccurrence;
- Provide guidance to ensure compliance with applicable technical standards;
- Set specific responsibilities and activities for laser safety, training, and medical evaluation.

This manual states the organizational responsibilities and procedural safety requirements of the KAUST Laser Safety Program with special emphasis to all Class 3B and Class 4 lasers and lower class systems containing embedded Class 3B and Class 4 lasers (embedded lasers). Adherence to the written program detailed in this manual and associated documents will ensure that the devices are handled safely. Failure of any individual to comply with requirements can cause injury as well as jeopardize the research, the laboratory involved, and the institution.

2. ORGANIZATION AND RESPONSIBILITIES

2.1. Health, Safety, and Environment (HSE)

The Research Safety Team (RST), which is part of the Health, Safety and Environment (HSE) department at KAUST, manages and implement all research safety programs including the Laser Safety Program. The RST is responsible for providing up-to-date information and training as well as ensuring day-to-day operations and compliance with the various safety programs (i.e. general safety advice, inspections of laboratories, assistance when incidents occur, etc.). Authority for oversight of the Laser Safety Program is given to the Laser Safety Officer (LSO).

2.1.1. Laser Safety Officer (LSO)

- Develop, implement and regularly update the Laser Safety Program;
- Maintain an inventory of Class 3B and Class 4 laser systems (including equipment containing embedded Class 3B and Class 4 laser systems);
- Develop laser safety training;
- Conduct Laser Hazard Evaluations as well as laser system and laser area inspections for Class 3B and Class 4 laser systems;
- Register Class 3B, and 4 laser installation facilities and laser equipment (including equipment containing embedded Class 3B and Class 4 laser systems) prior to use;
- Review Standard Operating Procedures (SOPs), including alignment procedures that may be subject to administrative and procedural controls;
- Classify or verify the classification of constructed or modified lasers and laser systems;
- Provide guidance and support regarding laser laboratory design and upgrades to ensure safe and effective working environments in compliance with the Laser Safety Program;
- Provide recommendations and guidance for laser safety including administrative controls, engineered devices, and personal protective equipment (PPE);
- Develop and update laser safety documents complementary to the manual;
- Review transfers and disposal of Class 3B and Class 4 laser systems as well as equipment containing embedded Class 3B and Class 4 laser systems;
- Investigate laser incidents, injuries and advise on corrective actions;
- Suspend, restrict, or terminate the operation of a laser system as decided in consultation with the RST Manager / Director of HSE.

2.2. Laboratories

2.2.1. Principal Investigator or Center Director

The primary responsibility for ensuring safe conduct and safe environment in the laboratory resides with the Principal Investigator (PI) or Center Director who has the custody of the laser systems. Those responsibilities include:

- Inform the LSO of purchase/acquisition for each Class 3B and Class 4 laser as well as equipment containing embedded Class 3B and Class 4 laser system;

- Maintain an up-to-date list of registered laser devices, rooms where the devices are used or stored. The list of registered laser devices should be maintained;
- Maintain names of personnel who are authorized to use registered laser systems as well as their training records;
- Designate a Laser Safety Contact (LSC) knowledgeable in each laser or laser system in the laboratory. The LSC is the laboratory liaison to the LSO. The LSC can be the PI, research staff or students designated by the PI;
- Schedule with the LSO the inspection of the laser area and laser system required to complete the laser registration;
- Contact the LSO:
    - Regarding purchase of Class 3B, Class 4 or equipment containing embedded Class 3B or Class 4 laser systems;
    - If a laser is re-located to a different laser laboratory;
    - Before starting a new procedure that varies from the previous protocols;
    - Before renovating, altering, repairing or vacating any laboratory space that could affect the use and safety of the laser device(s);
    - Before changing laboratory locations or leaving the University;
    - Before transferring or disposing of any registered laser device;
- Develop, implement and submit to the LSO the current Standard Operating Procedures (SOPs) and if required alignment procedures for each Class 3B and Class 4 laser or laser system using the Laser SOP template as a guide;
- Ensure that lasers are operated in accordance with established safety procedures (i.e. registration conditions, SOPs, and the Laser Safety Manual, manufacturer's manuals, etc.);
- Ensure that all authorized personnel, who are eligible to operate (or maintain) a Class 3B or Class 4 laser or laser system, complete laser safety training and other applicable occupational health requirements and are familiar with the laser safety procedure for their laser system prior to initial operation;
- Develop and provide equipment specific safety training to each laser user (including physical hazards, health hazards, and emergency procedures). A template of Equipment Specific Safety Training form is shown in Appendix B;
- Purchase/provide all engineering controls and PPE devices recommended during the Laser Hazard Evaluation or during laboratory modification request discussions;
- Ensure that all Personal Protective Equipment (PPE) and laser safety devices are functioning properly and checked regularly;
- Control laser exposures to the user, the University Community, and general public;
- **Immediately** notify the LSO and/or Research Safety Team of unsafe conditions, and all known or suspected laser related incidents;
- Inform visitors to areas or laboratories where lasers are present of the hazards and control measures associated with these systems and give proper eyewear, as appropriate, to the visitors.

2.2.2. Laser Safety Contact (LSC)

The Laser Safety Contact (LSC) is a qualified laser user within the same group appointed by the PI or Center Director to assist him/her to ensure compliance with all laser safety policies and procedures. The LSC oversees the day-to-day laser safety in the laboratory environment. The LSC must have the appropriate education, training, and practical experience commensurate with the laser sources to be used. The LSC is the point of contact for that laboratory on laser safety related issues.

Each LSC shall be delegated authority in regard to laser safety matters by the PI or Center Director. The appointment of a LSC does not diminish the particular responsibilities of the PI or Center Director. The main roles of the LSC are to:

- Assist the PI or Center Director to meet their responsibilities for laser safety and compliance as described in the Laser Safety Program;
- Act as a point of contact for all laser safety matters arising at the particular location.

2.2.3. Laser Users

Laser users are PI, staff, students or visitors who in the management system have been assigned in their job activities "Work with Class 3B and 4 lasers". These individuals have been identified and authorized to operate and/or maintain/service Class 3B or Class 4 laser systems as well as maintain/service equipment containing embedded Class 3B and Class 4 laser systems. As a result, they are responsible for complying with relevant portions of this Laser Safety Program. *Particular emphasis is placed upon those laser operators who are involved with beam alignment and use of open beam systems.* In addition, anyone who must enter a laboratory for work with a registered laser, but who is not authorized to work with these devices, must do so under the direct supervision and presence of a laser user from that laboratory. All laser users must also:

- Complete the appropriate required training (General safety course and equipment-specific training). At present there are no refresher trainings but it is highly recommended that laser users retake the training regularly (e.g. every 3 years);
- Be registered/identified by the PI or Center Director as using registered lasers;
- Comply with all established safety rules detailed in the Laser Safety Manual, SOPs and any manufacturer's laser-specific safety guidelines for the laser he/she is operating ;
- Wear appropriate laser protective eyewear and other PPE as necessary;
- Ensure that any other persons within the Nominal Hazard Zone (NHZ) of the laser are also wearing appropriate eyewear if necessary;
- Use all available laser safety controls (e.g. close laser curtains, use beam blocks, use low power for alignment procedures, etc.…) to minimize radiation exposure;
- Know and follow emergency procedures;
- **Immediately** notify the LSC, PI or Center Director and LSO of unsafe conditions, and all known or suspected laser related incidents.

2.3. Core Labs

The Lab Equipment Maintenance (LEM), Research Infrastructure Strategy and Planning (RISP) and Research Asset Support (RAS) teams are part of the Core Labs.

2.3.1. Lab Equipment Maintenance (LEM)

The Lab Equipment Management (LEM) team has a dedicated group that is responsible for:

- Maintaining/Servicing and installing equipment from preferred manufacturers or from manufacturers that have an agreement with KAUST;
- Providing the technical support to laser users and research groups;
- Assisting PIs or Center Directors in selecting the appropriate lasers;
- Completing the “LEM comments” sections of the Capital Equipment Form/Proposal for Academic Space and Equipment Planning Committee (ASEPC);
- Clearing shopping carts relating to the purchase of laser systems on the procurement system;
- Working with the LSO to provide laser technical and laser safety advices.

2.3.2. Research Infrastructure Strategy and Planning

The Research Infrastructure Strategy and Planning (RISP) team is responsible for:

- Reviewing and assessing all Capital Equipment Proposals prior to ASEPC’s approval;
- Overseeing the implementation of the ASEP Committee’s decisions;
- Working with the Research Asset Support team for the KAUST research community;
- Keeping the LSO informed of the acquisition of new laser or transfer/disposal of laser equipment.

2.3.3. Research Asset Support

The Research Asset Support (RAS) team is responsible for:

- Keeping an up to date inventory of all asset equipment on KAUST research spaces;
- Managing the asset equipment, this include adding asset tags, etc.
- Assisting PIs/Center Directors with the removal of equipment following transfer/donation or disposal request.

3. TRAINING

3.1. Laser Users Requirements

In order to become a laser user, the person must complete the following:

- Complete the Laser Safety Training via the online system and pass the associated quiz;
- Complete the equipment specific safety training provided by the laboratory;
- Read and understand the SOPs for the laser(s) they will use.

Table 1 summarizes under which circumstances laser users need to fulfill the requirements stated above. Note that these trainings are not required for users of Class 1 to 3R lasers but these are recommended.

Table 1. Training requirements for laser users.

	Normal operation of the laser equipment	Maintenance/service of the laser equipment
Class 3B laser	Required	Required
Class 4 laser	Required	Required
Equipment containing embedded Class 3B/4 lasers	Not Required	Required
Class 1M – 3R	Not Required	Not Required

3.2. Laser Safety Training

All Laser Safety Contacts (LSC) and laser users shall be trained in the safe use of lasers prior to beginning work with Class 3B and Class 4 lasers. Note that users who only operate an equipment containing embedded lasers under normal conditions are recommended, but not required, to complete the general Laser Safety Training.

The Laser Safety Training is offered online via an online system and the person must take the associated quiz. The quiz has a passing score of 100% but multiple attempts are allowed. On-demand live training sessions can also be provided for groups of 5 or more. To organize an on-demand training, please contact HSE@kaust.edu.sa.

3.3. Laser Safety Awareness Training

Students and personnel working near lasers or with Class 1 (with interlock operating) to Class 3R lasers are recommended to take the Laser Safety Awareness Training.

The Laser Safety Awareness Training is offered online via an online system and the person must take the associated quiz. The quiz has a passing score of 100% but multiple attempts are allowed.

3.4. Equipment Specific Safety Training

Each group or PI must provide laser users with equipment specific safety training for each Class 3B and Class 4 laser they will use. The training should include a range of topics from how to switch on and switch off the system, safety measures associated with the laser's system, non-beam hazards' safety measures in place, etc. (see Appendix B or Equipment Specific Safety Training Form). It is essential that new or less involved laser users are provided with operational training by an individual fully aware of the nature of the work and the hazards involved. Equipment specific safety training is also required for users who are allowed to maintain/service equipment containing embedded Class 3B and Class 4 lasers. In addition, as part of this training, the laser users must read and understand the SOPs associated with the equipment and sign them.

3.5. Training Records

All training must be documented for record keeping purposes. Laser Safety Training and Laser Safety Awareness Training records are maintained automatically via the online system. Departments are responsible for maintaining the equipment specific safety training records.

4. LASER ACQUISITION, REGISTRATION, TRANSFER OR DISPOSAL

All Principal Investigators (PI) or Center Directors who own and use/store Class 3B and Class 4 laser systems as well as equipment containing embedded Class 3B and Class 4 laser systems must register them with the LSO before initial use. The best time to start that process is when the laser is ordered.
A process map of the main laser safety requirements is shown in Appendix C.

4.1. Laser Acquisition

At KAUST, all equipment including laser systems, must be purchased via the Procurement System; however, depending on the total cost of the equipment additional approvals are required.

- Purchase of laser systems with a total cost equal or in excess of $ 20,000 (this includes the equipment price, shipment cost and associated costs such as taxes, import, etc.), must be authorized/approved by the Academic Space and Equipment Planning Committee (ASEPC). In order to purchase such equipment, the PI or Center Director must complete an ASEPC Application Form which is reviewed by the committee. If approved, then Research Infrastructure, Strategy and Planning (RISP) team places the order on the behalf of the PI or Center Director.
- Purchase of laser systems with a total cost below $20,000 can be done directly by the PI or Center Director via the Procurement System. As part of this process, all these shopping carts must be cleared by the Lab Equipment Maintenance (LEM) team.

The PI or Center Director is required to notify the LSO via email (directly to the LSO or to HSE@kaust.edu.sa) of any purchase of Class 3B or Class 4 laser systems (and if possible to provide the equipment datasheet/specifications or user manual). For more information on this topic, please refer to the Laser Purchase Procedure.
It is recommended that the notification to the LSO is done before the equipment is purchased. If the equipment does not comply with ANSI standards, additional cost may be necessary to improve the laser safety. Before the laser purchase, the PI or Center Director is also encouraged to contact the specialized LEM team who can advise and help find the laser system that meets the necessary requirements in terms of safety and maintenance regime.

4.2. Laser Registration

All Class 3B, Class 4 and equipment containing embedded Class 3B and Class 4 lasers shall be registered with the LSO (Figure 1). The registration process is as follows:

1. Once the laser purchase is finalized, the PI or Center Director must send an email to notify HSE (HSE@kaust.edu.sa). For example, if the system purchased contains a pump laser and the actual laser oscillator then two registrations will be completed;
2. The LSO uses the provided information to carry out the Laser Hazard Evaluation;
3. The PI receives the laser system and must ensure that the equipment is allocated an asset tag number by emailing AssetManagement@kaust.edu.sa. Again, if the system contains two lasers (a pump and the oscillator) the Research Asset Support (RAS) team should allocate two tags - one for each laser;

4. The PI or Center Director informs the LSO once the laser is delivered and/or installed in the laboratory;
5. The LSO may visit the laboratory to review the installation and control measures in place. At this stage if additional control measures are required the PI or Center Director will be informed. perform the Tier 3 Laser Safety Assessment and checks the updated list of laser users. During this visit the LSO checks that all required control measures are in place;
6. The PI or Center Director send the SOP and [Laser Parameters Measurement Form (voluntary)]() to the LSO for review.
7. When all control measures are in place, the LSO preforms a Tier 3 Laser Assessment and checks the updated list of laser users. During this visit the LSO checks that all required control measures are in place. When Satisfied, the LSO finalize the registration.

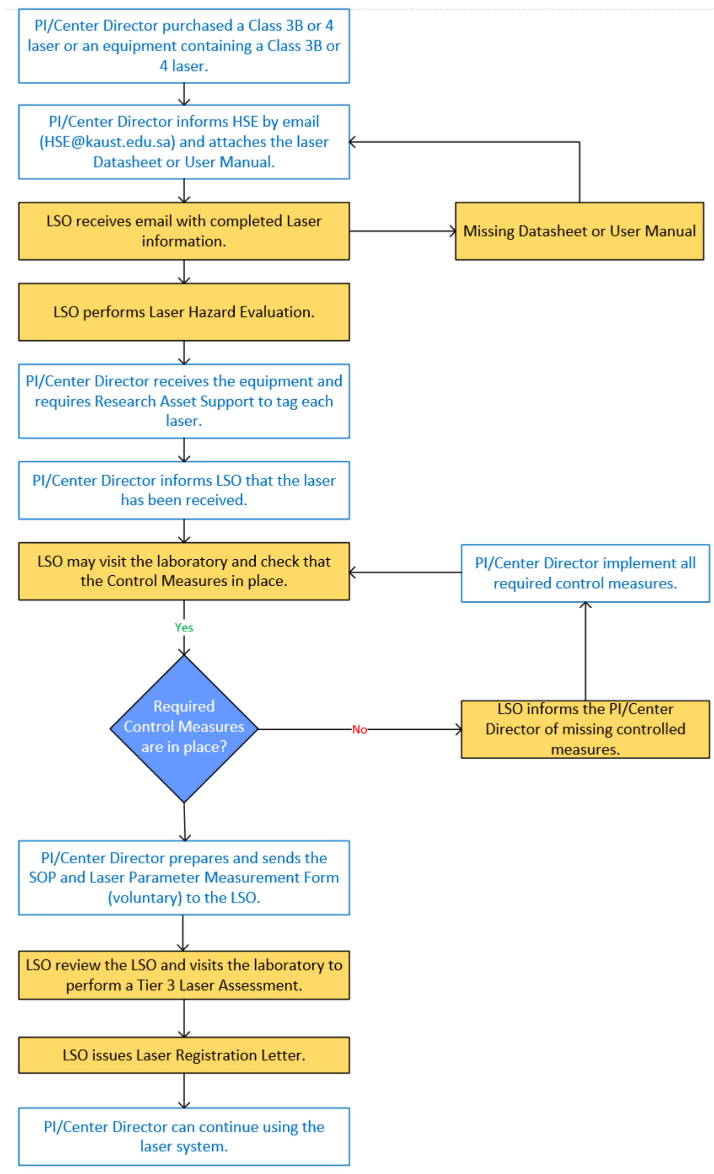


Figure 1. Laser registration process.

If significant modifications are made to an original laser/laser system, or the laser system is moved, or the experimental set-up is altered, the laser must be re-registered. All laser users working with the modified laser/experiment shall be trained on the modifications.

4.3. Laser Transfer or Disposal

If a laser remains under the possession of the same PI/Group but its location is moved, the PI/Center Director or LSC must inform the LSO by email (directly or via HSE@kaust.edu.sa).
If a laser system is transferred (to a new PI or surplus) or disposed, please notify the LSO via email (directly or via HSE@kaust.edu.sa). The LSO will provide you with appropriate transfer or disposal instructions. Additional information can also be found in the Laser Transfer/Donation and Disposal Procedure.

5. LABORATORY DESIGN

The PIs or Center Directors shall engage with the Engineering & Project Management Department, LEM and the LSO as soon as possible when planning new additions or modifications to a laser laboratory in order to ensure that laser safety control measures are included in the price estimation and plans (see Guidance on Laser Laboratory Design). For more information on the common control measures implemented in laser laboratory please refer to the section below.

6. CONTROL MEASURES

Control measures are designed to reduce the possibility of eye and skin exposure above the Maximum Permissible Exposure (MPE) limit and other hazards associated with lasers. The hazards associated with the use of lasers are covered in a separate document named Laser Hazards. The ANSI Z136.1 standard requirements for control measures are summarized in Appendix D and the general laser safety precautions by class are presented in Appendix E.
Control measures are classified as engineering, administrative and personal protective equipment (PPE) and are based on normal operation of the laser system. Engineering controls are always the preferred method to provide safety. Administrative and PPE control measures are used to complement the engineering controls. However, it is common in laser laboratories that all 3 types of controls are implemented to ensure an appropriate level of safety.
When maintenance or service is performed, additional control measures are often necessary to address additional safety requirements.

6.1. Class 1 to Class 3R Laser Systems Control Measures

When used as intended Class 1, 1M, 2, 2M and 3R laser systems are generally low hazard devices. These do not need to be registered with the KAUST LSO; however some requirements still apply. The PIs or Center Directors are responsible for:

- Ensuring users are trained on proper use of the equipment;
- Ensuring laser systems (Class 2 and above) have the appropriate warning labels with the laser sunburst symbol and cautionary statement. If unsure, advice from the LSO can be requested;
- Ensuring the safe operating conditions during operation and maintenance of the laser systems;

- Informing the LSO prior to servicing the equipment or modifying the system (e.g. removal of protective housing, etc.) so the existing control measures can be reviewed. Note that system modification can increase a laser's classification;
- Preparing an SOP detailing safety measures for the use of optical aides for Class 1M, 2M and 3R lasers (this is a recommendation);
- Adding a warning sign at the lab entrance and/or near the experiment if lasers Class 2 to Class 3R are left unattended. Warning signs for Class 2 to Class 3R laser are available on the website.

6.2. Equipment Containing Embedded Class 3B and Class 4 Laser Systems (Equivalent to Class 1)

There are no required control measures for embedded and interlocked Class 3B and Class 4 laser systems, except laser registration. However, ANSI recommends that warning signs are posted on the equipment stating that the protective housing must not be removed or tampered with and that the interlock must not be defeated. If either of these actions take place, the laser is no longer classified as a Class 1 and the control measures stated in section 6.3 apply. Removing/tampering with the interlocks or protective housing may results in disciplinary actions if the users are not allowed to do so.

6.3. Class 3B or Class 4 Laser Systems Control Measures

The operation and maintenance of Class 3B and Class 4 laser systems requires more stringent control measures to be in place.
For Class 3B and Class 4 laser systems, a Laser Hazard Evaluation must be performed by the LSO and a Laser Controlled Area (LCA) shall be designated for all open and partially open beam paths in laboratories. The LCA is defined as the area where the level of laser radiation exceeds the MPE level. Typically the LCA is defined by the room walls, floor and ceiling or an area delimited with laser-proof curtains.

At KAUST, the recommended control measures to be in place during the operation of Class 3B and Class 4 laser systems in the LCA are detailed below. Some or all of these may be implemented depending on the Laser Hazard Evaluation and laser use.

6.3.1. Laser Registration

All Class 3B and Class 4 laser systems must be registered including equipment containing embedded Class 3B and Class 4 laser system (see section 4.2).

6.3.2. Room Access Controls

The entry to areas where Class 3B and Class 4 laser systems are used must be controlled so that only registered laser users are allowed. In addition, the controls in the LCA must be designed to allow rapid egress by laser users and emergency responders under emergency conditions. There are different type of controls available:

- Non-Defeatable Entryway Controls – Opening the entryway will cause the laser system to become safe due to a drop in power or blocking of the laser beam to a safe level (i.e. below MPE). No individual shall be able to defeat the entryway controls.

- Defeatable Entryway Controls – Opening of the entryway, will cause the laser system to become safe due to a drop in power or blocking of the laser beam to a safe level (i.e. below MPE); this may be the case in an emergency situation or if unauthorized personnel try to enter while the interlock is activated. However, the system can be defeated to enable laser users to enter/exit the area safely without interrupting the laser operation. Note that at KAUST, this is the preferred system and the connection to the laser power supply is not compulsory (i.e. it will only be done if the PI or Center Director requests it). This system provides a secure entry/exit method to the Laser Controlled Area. Staff must be trained and provided with PPE before the entrance.
- Procedural Entryway – In areas where safety interlocks is not practical, all personnel authorized to access shall be adequately trained and the appropriate PPE shall be available upon entry. In addition, in such cases, the level of laser radiation at the entry shall be below the MPE, which can be accomplished by installing laser barriers/curtains.

6.3.3. Illuminated Warning Sign

A warning light shall be placed at the entry of any Laser Controlled Area. The device, which must be placed at eye level, must only be illuminated when the laser is operational.

6.3.4. Laser Protective Barriers and Curtains

A physical barrier, screen or curtain that can block or filter the beam must be used to prevent laser radiation from exiting the LCA at levels above the MPE (e.g. around the experimental set-up, to demarcate the Laser Controlled Area or to protect the entryway). This also includes the requirement to cover any windows, doorways, open portals in the LCA that is within the Nominal Hazard Zone (NHZ). These barriers, screens or curtains must be able to withstand direct or diffusely scattered beams. If these are not an integral part of a product, they shall be labelled with the exposure for which the limit applies and the exposure beam condition under which protection is afforded. If the windows are covered with filters, the latter shall be labelled with the optical density and wavelength for which the protection applies.

6.3.5. Beam Path Controls

If the laser beam path is fully or partially open, the LSO must carry out a Laser Hazard Evaluation and control measures will be required to ensure personnel are not exposed to levels exceeding the MPE. Examples of such control measures would be to use an anodized beam pipe to enclose the beam path or to use laser-proof screens/curtains to surround the whole experiment and enclose the beam path, etc.
In addition, it is recommended that only diffusely reflecting materials are used in or near the beam path.

6.3.6. Beam Path Termination

Any potentially hazardous beam must be terminated using a beam stop or attenuator. However, considerations must be given to the material composition of the beam stop or attenuator to minimize the risk of fire or heat damage to the material.
Beam attenuators are also of great use during alignment procedures as they can reduce the output level below the MPE, thereby allowing the laser user to operate the system without the need for protective eyewear.

6.3.7. Laser Radiation Emission Indicator

The laser control panel should have a warning device that activates when the laser is operational. The laser warning device can consist of audible sound, warning light, etc. In the ANSI standard, the emission indicator is required for Class 4 laser systems and recommended for Class 3B laser systems.

6.3.8. Emergency Stop

For emergency conditions, the laser should be equipped with a means to deactivate or reduce laser emission below the MPE level. The emergency stop is often represented by the red mushroom button but it can also be achieved by turning the control key to the off position or other methods.

6.3.9. Key Control

Class 3B and Class 4 lasers should be provided with a master switch (i.e. either a key control or coded access). The latter must be disabled when the laser is not in use to prevent unauthorized use.

6.3.10. Education and Training

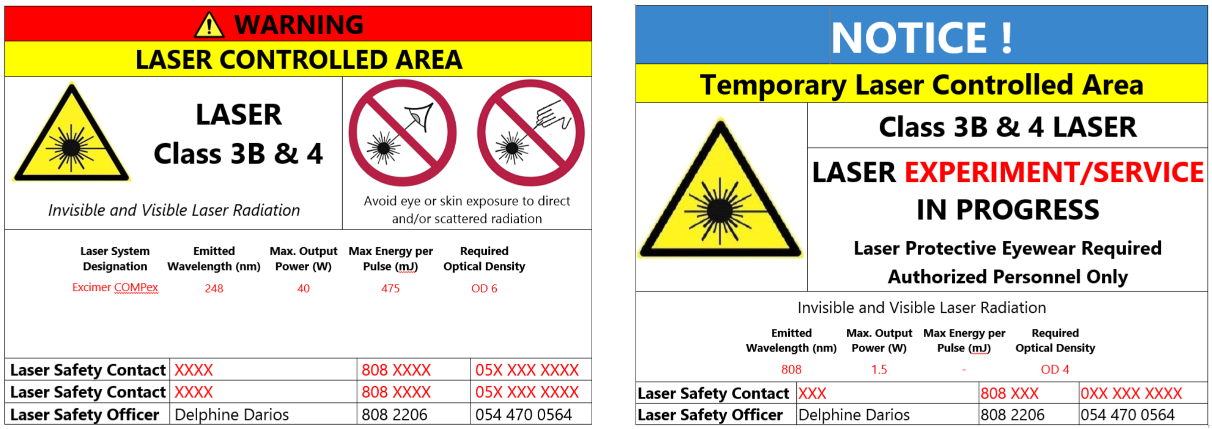
The personnel operating, maintaining and servicing Class 3B and Class 4 laser systems must have completed the required laser safety trainings and been added to the list of laser users. The required trainings are detailed in section 3.

6.3.11. Warning Sign Posting

Areas where Class 3B and Class 4 lasers are used shall have proper warning indication to prevent accidental exposure to the beam. It is the responsibility of the PI or Center Director to display and maintain the proper signage. The warning sign must include specific information regarding the laser hazards and be posted near the entrance to any area or laboratory that contains a Class 3B or Class 4 laser or laser system. The sign and the wording must be commensurate with the highest-class laser contained within the area or laboratory. An example of the KAUST warning sign for a Laser Controlled Area is shown in Figure 2.

During maintenance or service of an equipment containing embedded Class 3B and Class 4 laser systems, a temporary Laser Controlled Area must be defined and the associated warning sign (Figure 2) must be posted at the entrance.

The Laser Controlled Area and Temporary Laser Controlled Area warning signs can be downloaded from the Laser Safety webpage.



(a) (b)

Figure 2. (a) Example of a laser warning sign placed at the entrance of a Laser Controlled Area, (b) Example of a temporary Laser Controlled Area Warning Sign.

6.3.12. Standard Operating Procedures (SOPs)

Written laser safety procedures, also called SOPs, are required for Class 3B and Class 4 laser systems and must be reviewed by the LSO. The procedures address both beam and non-beam hazards as well as alignment procedures (see Appendix G for information on alignment procedures), emergency procedures, etc. All laser users are required to be familiar with the SOPs associated with their system. The SOPs must be kept with the laser equipment for reference by operators or service personnel and can be used as instructional material to train new laser users in the facility. All SOPs must be updated to reflect any changes in laser setting or equipment usage.

In the case of enclosed system (e.g. laser scanning confocal microscope) the requirement for an SOP may be reduced or waived entirely after a review by the LSO. A template SOP is available on the Laser Safety webpage.

6.3.13. Equipment Label

Labelling of lasers

All lasers, except Class 1, are required to contain warning labels affixed to a conspicuous place on both the housing and the control panel (if separated by more than 2 meters). The labels shall contain the laser sunburst logo and the appropriate cautionary statement. Modified or constructed laser systems at KAUST shall be provided with labels that are clearly visible during operation and be affixed to the laser housing or control panel as for manufactured laser systems. According to ANSI standard, the lasers and laser systems shall have an equipment label that includes the following information:

- The class of laser or laser system;
- The emitted wavelength, pulse duration (if appropriate) and maximum output power;
- A precautionary statement for users such as:
  - Class 2 lasers and laser systems, “Laser Radiation – Do Not Stare into Beam”
  - Class 2M lasers and laser systems, “Laser Radiation – Do Not Stare into Beam or View Directly with Optical Instruments”
  - Class 3R and 3B lasers or laser systems, “Laser Radiation – Avoid Direct Eye Exposure to Beam”

- Class 4 lasers or laser systems, “Laser Radiation – Avoid Eye Exposure to Direct or Scattered Radiation; Avoid Skin Exposure to Direct Radiation”

Ancillary hazards shall also be appropriately labeled such as protective eyewear, windows, barriers and curtains, etc.

Labeling of Protective Eyewear

All eyewear must be clearly labeled with the optical density (OD) and wavelength for which protection is afforded. Color-coding or other distinctive identification is recommended in multi-laser environments.

Labeling of Laser Protective Windows and Collecting Optic Filters

All laser protective windows, sold other than as an integral part of a product, must be labeled with the optical density (OD) and wavelength(s) for which protection is afforded. They should also be labeled with the threshold limit and exposure time for which the limit applies, and the conditions under which protection is afforded.

Labeling of Laser Protective Barriers

All laser protective barriers, sold other than as an integral part of a product, must be labeled with the barrier exposure time for which the limit applies, and beam exposure conditions under which protection is afforded.

If have any question, please contact the LSO for any assistance.

6.3.14. Personal Protective Equipment (PPE)

Appropriate personal protective equipment (PPE) are required for Class 3B and Class 4 lasers if the potential beam and non-beam hazards cannot be eliminated with the engineering and administrative controls already in place. PPE for laser safety purposes commonly used are laser protective eyewear, face shields, protective clothing, and respiratory protection for Laser Generated Air Contaminants (LGAC).

All protective equipment should be maintained regularly including cleaning, visual inspection and proper storage in order to ensure the greatest possible protection for laser users in the workplace.

Additional information is provided in Appendix F but it is recommended that the LSO is consulted to provide guidance on selection of appropriate laser protective eyewear for each laser.

Laser Eye Protection

Laser eye protection shall be used for Class 3B and Class 4 lasers; however, they are usually not required for Class 2 or Class 3R lasers or laser systems, except in conditions where intentional long-term (>0.25 seconds) direct viewing is required. Note that PPE has serious limitations when used with high-powered or ultra-short pulses Class 4 lasers and may be insufficient to reduce or eliminate the hazard and may be damaged by incidental laser radiation. PPE should not be used as the only control measure with Class 4 lasers.

Skin Protection

Skin protection should be considered for Class 3B and Class 4 lasers and laser systems, especially if those emit ultraviolet radiation which is known to cause skin cancer. This can be easily accomplished through the use of face shields, laboratory coats, coveralls and cotton gloves. It is also recommended to consider flame retardant materials. For other wavelengths such as IR, these items may not provide adequate protection and the use of curtains and screens may be needed to protect the skin.

7. MEDICAL SURVEILLANCE

Laser operators or individuals who work routinely in laser environments containing a Class 3B or Class 4 lasers do not need to be enrolled in a medical surveillance program.

Medical surveillance evaluations should occur: in the event of any laser exposure (see section 8), and if requested by the user.

8. EMERGENCY PROCEDURES

In case of an emergency involving another person or a laser device/experimental set-up, the laser user(s) present must switch off the laser by turning the key switch off and blocking all laser apertures. Then depending on the emergency, the laser users must act as described in the sections below.

8.1. Emergency Involving Personnel

In the event of an overexposure of a person to laser radiation, the following steps should be taken:

- Stay with the injured person (if it is safe to do so);
- Report to KAUST health emergency room as soon as possible (within 48 hours) to ensure that the effected person(s) receive(s) medical treatment. If immediate assistance is required, call 911 (KAUST landline) or 012-808-0911 (mobile phones) and indicate the location of the incident and if an ambulance is needed. Do not hang–up until you are told to do so;
- If accidental exposure to the eye has occurred, complete the Laser Eye Injury Description Form and take it to KAUST Emergency Room (if possible);
- The injured individual must report to their PI or Lab Safety Representative. The injured individual should report the incident using the online reporting system.

8.2. Non-Personnel Emergency

8.2.1. Fire

In case of **Fire,** the laser user must:

- Isolate the laser system from the main power supply (if it is safe to do so);
- Activate the fire alarm by pulling the nearest fire alarm pull station;
- Evacuate the laboratory and inform others in the vicinity;
- Call 911 (KAUST landline) or 012-808-0911 (mobile phones) and indicate the location of the incident and if an ambulance is needed. Do not hang–up until you are told to do so;
- Close all doors when leaving;
- Report to the designated assembly point;
- Do not re-enter the laboratory until you have been told it is safe to do so;
- Log the incident in the reporting system;
- Collaborate with the LSO/RST to investigate the cause of the incident.

8.2.2. Flood

In case of **Flood**, the laser user must:

- Isolate the laser system from the main power supply (if it is safe to do so);

- Call 911 (KAUST landline) or 012-808-0911 (mobile phone) and indicate your location of the incident and if an ambulance is needed. Do not hang–up until you are told to do so;
- Evacuate the laboratory and do not allow anybody in the laboratory until it is safe;
- Contact the PI, LSC, and LSO;
- Log the incident in the reporting system;
- Collaborate with the LSO/RST to investigate the cause of the incident.

8.2.3. Equipment Malfunction

In case of **Equipment Malfunction,** the laser user must:

- Isolate the laser system from the main power supply (if it is safe to do so);
- Place a notice on the laser device to indicate "EQUIPMENT MALFUNCTION- DO NOT USE UNTIL FURTHER NOTICE";
- Contact the PI, LSC, and LSO;
- Contact the manufacturer or LEM to have the laser serviced;
- Log the incident in the reporting system;
- Collaborate with the LSO/RST to investigate the cause of the incident.

References

Standards

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

ANSI Z136.8, American National Standard for Safe Use of Lasers in research, development, or Testing, 2012.

US and EC Standards for Laser Safety, http://www.laserproductsafety.com/lpssr.htmRoy Henderson and

Books

Karl Schulmeister, *Laser Safety* (2004).

Ken Barat, *Laser Safety Management* (2006).

Ken Barat, *Laser Safety – Tools and Training* (2009).

Ken Barat, *Laser Safety in the Lab* (2013).

Useful webpages

Laser Institute of America (LIA), www.lia.org

Rockwell Laser Industries, https://www.rli.com/

University of Florida, http://www.ehs.ufl.edu/programs/rad/laser/

Harvard University, https://www.ehs.harvard.edu/programs/lasers

Appendix A – Definitions

TERM	DEFINITION
Absorption	Transformation of radiant energy to a different form of energy by interaction with matter.
Accessible Emission Limit (AEL)	The maximum accessible emission level permitted within a particular laser hazard class.
Attenuation	The decrease in the radiant flux as it passes through an absorbing and/or scattering medium.
Average power	The total energy in an exposure or emission divided by the duration of that exposure or emission.
Aversion response	Closure of the eyelid, eye movement, pupillary constriction, or movement of the head to avoid an exposure to a noxious or bright light stimulant. In this standard, the aversion response to an exposure from a bright, visible, laser source is assumed to limit the exposure of a specific retinal area to 0.25 s or less.
Beam	A collection of light/photonic rays characterized by direction, diameter (or dimensions), and divergence (or convergence).
Beam diameter	The distance between diametrically opposed points in that cross-section of a beam where the power or energy is 1/e (0.368) times that of the peak power or energy.
Coherent	A light beam in which the electromagnetic waves maintain a fixed and predictable phase relationship with each other over a period of time and/or space.
Continuous Wave (CW)	A laser operating with or modeled as having a continuous output for a period ≥ 0.25 s is regarded as a CW laser.
Controlled Area	An area where the occupancy and activity of those within is subject to control and supervision.
Cornea	The transparent outer layer of the human eye that covers the iris and the crystalline lens. The cornea is the main refracting element of the eye.
Diffuse reflection	Change of the spatial distribution of a beam of radiation when it is reflected in many directions by a surface or by a medium.
Diffraction	Deviation of part of a beam determined by the wave nature of radiation and occurring when the radiation passes the edge of an opaque obstacle.

TERM	DEFINITION
Embedded laser	An enclosed laser that has a higher classification than the laser system in which it is incorporated, where the system's lower classification is appropriate due to the engineering features limiting accessible emission.
Enclosed laser	A laser that is contained within a protective housing of itself or of the laser or laser system in which it is incorporated. Opening or removal of the protective housing provides additional access to laser radiation above the applicable MPE than possible with the protective housing in place.
Hertz (Hz)	The unit that expresses the frequency of a periodic oscillation in cycles per second. The term also describes the number of repetitive pulses occurring per second.
Irradiance	Radiant power incident per unit area upon a surface, expressed in watts per centimeter squared ($W.cm^{-2}$).
Joule (J)	A unit of energy. 1 Joule = 1 Watt second (W.s)
Laser	An acronym for **L**ight **A**mplification by **S**timulated **E**mission of **R**adiation. A device that produces radiant energy predominantly by stimulated emission. Laser radiation may be highly coherent temporally, or spatially, or both.
Laser Pointer	A laser or laser system designed or used to specify a discrete point or location, such as those lasers used in classroom lectures or for the aiming of firearms. These products are usually Class 1, Class 2, or Class 3R.
Limiting aperture	The diameter of a circle over which irradiance or radiant exposure is averaged for purposes of hazard evaluation and classification.
Maximum Permissible Exposure (MPE)	The level of laser radiation to which an unprotected person may be exposed without adverse biological changes in the eye or skin.
Nominal Hazard Zone (NHZ)	The space within which the level of the direct, reflected, or scattered radiation may exceed the applicable MPE. Exposure levels beyond the boundary of the NHZ are below the applicable MPE.
Nominal Ocular Hazard Distance (NOHD)	The distance along the axis of the unobstructed beam from a laser, fiber end, or connector to the human eye beyond which the irradiance or radiant exposure does not exceed the applicable MPE.
Protective housing	An enclosure that surrounds the laser or laser system and prevents access to laser radiation above the applicable MPE. The aperture through which the useful beam is emitted is not part of the protective housing. The protective housing limits access to other associated radiant energy emissions and to electrical hazards associated with components and terminals, and may enclose associated optics and a workstation.

TERM	DEFINITION
Pulse duration	The duration of a laser pulse, usually measured as the time interval between the half-power points on the leading and trailing edges of the pulse. Typical units: Microsecond (µs) = 10^{-6} s Nanosecond (ns) = 10^{-9} s Picosecond (ps) = 10^{-12} s Femtosecond (fs) = 10^{-15} s
Pupil	The variable aperture in the iris through which light travels to the interior of the eye.
Q-switch	A device for producing very short (10-250 ns) intense laser pulses by enhancing the storage and dumping of electronic energy in and out of the lasing medium, respectively.
Radian (rad)	A unit of angular measure equal to the angle subtended at the center of a circle by an arc whose length is equal to the radius of the circle. 1 rad=57.3°.
Radiance (L)	Radiant flux or power per unit solid angle per unit area expressed in watts per centimeter squared per steradian ($W.cm^{-2}$. Sr^{-1}. Symbol: L).
Radiant energy (Q)	Energy emitted, transferred, or received in the form of radiation. Unit: joules (J), Symbol: Q.
Radiant exposure (H)	Surface density of the radiant energy received, expressed in units of Joules per centimeter squared ($J.cm^{-2}$. Symbol: H).
Specular reflection	A mirror-like reflection.

Appendix B – Equipment Specific Safety Training Form

Equipment Specific Safety Training Form

Principal Investigator Name ______________________________

Laser Safety Contact Name ______________________________

Group ______________________________

Training done by

☐ Manufacturer ☐ PI ☐ LSC ☐ Other (give details) ____________________

Training for equipment

Manufacturer	Model	Serial Number	Asset Tag	Location (e.g. B4-0250)

Topic covered

☐ Laser Area, Nominal Hazard Zone, warning signs and labels

☐ Personal Protective Equipment (include appropriate choice of eyewear and location)

☐ Interlock system operation (if applicable)

☐ Beam hazards

☐ Non-beam hazards

☐ Switch equipment ON

☐ Switch equipment OFF

☐ Emergency stop and deactivation of the system

☐ Normal operation of the system

☐ Alignment procedure

☐ Accident Reporting

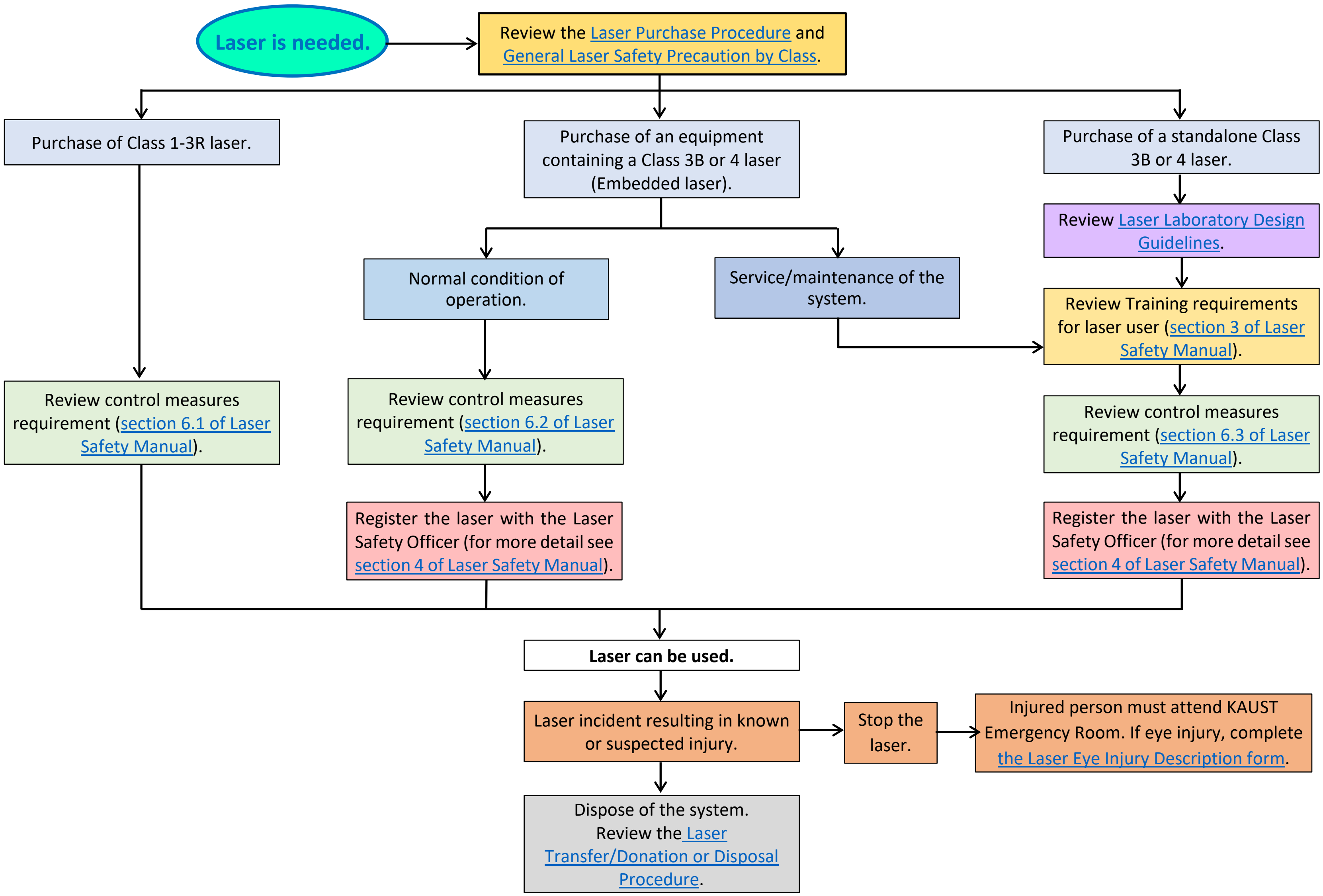
☐ SOP read, understood and signed by the trained person

☐ Other topic covered (give details below)

Person trained

Name	KAUST ID	Date of Training Completed

Appendix C – Laser Safety Program Process Map



Appendix D – ANSI Table of Control Measures

This summary is taken from the ANSI Z.136.1-2014. Reference numbers in parentheses refer to sections in the standard.

Table 1. Engineering Control Measures

Control Measures	**Laser Classification**						
	1	**1M**	**2**	**2M**	**3R**	**3B**	**4**
Protective Housing (4.4.2.1)							
Without Protective Housing (4.4.2.1.1)	LSO shall establish Alternative Controls						
Interlocks on Removable Protective Housing (4.4.2.1.3)							
Service Access Panel (4.4.2.1.4)							
Key Control (4.4.2.2)							
Viewing Windows, Display Screens and Diffuse Display Screens (4.4.2.3)	Ensure the viewing is limited below MPE level						
Collecting Optics (4.4.2.6)							
Fully pen Beam Path (4.4.2.7.1)						NHZ	NHZ
Limited Open Beam Path (4.4.2.7.2)						NHZ	NHZ
Enclosed Beam Path (4.4.2.7.3)	No further controls required if the beam is enclosed in an interlocked protective housing						
Area Warning Device (4.4.2.8)							
Laser Radiation Emission Warning (4.4.2.9)							
Class 3B Laser Controlled Area (4.3.10.1)							
Class 4 Laser Controlled Area (4.3.10.2)							
Temporary Laser Controlled Area (4.4.3.5)	MPE	MPE	MPE	MPE	MPE		
Entryway Controls (4.4.2.10.3)							
Protective Barriers and Screens (4.4.2.5)							

Table 2. Administrative Control Measures

Control Measures	**Laser Classification**						
	1	**1M**	**2**	**2M**	**3R**	**3B**	**4**
SOPs (4.4.3.1)							
Education and Training (4.4.2)							
Authorized Personnel (4.4.3.3)							
Alignment procedures (4.4.5)							
Laser Eye Protection (4.4.4.1)							
Skin Protection (4.4.4.3)							
Laser Controlled Area Warning Signs (4.6)							

Legend		Shall
		Should / Recommended
		No Requirements
		Shall if enclosed Class 3B or Class 4
	MPE	Shall if MPE is exceeded
	NHZ	Nominal Hazard Zone analysis required

Appendix E - General Laser Safety Precautions by Class

Lasers are classified according to their potential to cause biological damage and depend on:

- Laser output energy or power;
- Laser emitted wavelength;
- Exposure duration;
- Cross-sectional area of the laser beam at the point of interest.

In addition to these general parameters, lasers are classified in accordance with the Accessible Exposure Limit (AEL), which is the maximum accessible level of laser radiation permitted within a particular laser class. The laser hazard classification is based on the potential for a laser to exceed the AEL and is described in Table 1.

Table 1: Laser Systems Classification scheme. ANSI Z136.1 2014

Class 1	These lasers are considered to be incapable of producing damaging radiation levels during operation, and exempt from any control measures. A Class 1 laser system may contain a more hazardous laser embedded in the enclosure, but no harmful levels of the laser radiation can escape the system enclosure during normal operation. For Class 1 lasers containing an embedded higher class of laser, the enclosure must be interlocked. *Precautions:* *No laser-specific safety precautions are necessary.*
Class 1M	These lasers are considered to be incapable of producing hazardous exposure conditions during normal operation unless the beam is viewed with collecting optics (e.g. telescope) and is exempt from any control measures other than to prevent potentially hazardous optically aided viewing. *Precautions:* *No laser-specific safety precautions are necessary.*
Class 2	These lasers have a maximum output power of 1 mW. They emit in the visible portion of the spectrum (400 nm to 700 nm) and eye protection is normally afforded by the aversion response. The maximum emitted *Precautions:* o *Do not allow anyone to stare continuously into the beam.* o *Do not point the laser into an individual's eyes.*
Class 2M	Emits in the visible portion of the spectrum (400 nm to 700 nm) and eye protection is normally afforded by the aversion response for unaided viewing. However, Class 2M is potentially hazardous if viewed with collecting optics (e.g. telescope). *Precautions:* o *Do not allow anyone to stare continuously into the beam.* o *Do not point the laser into an individual's eyes.*

Class 3R	These lasers have a maximum output power of 5 mW for visible wavelengths (400 – 700 nm) or an output power between 1 and 5 times the Class 1 power limit for wavelengths shorter than 400 nm (UV lasers) or longer than 700 nm (IR lasers). They are potentially hazardous under some direct and specular reflection viewing conditions if the eyes are appropriately focused and stable, but the probability of an actual injury is small. This laser will not pose either a fire hazard or diffuse reflection hazard. *Precautions:* o Do not aim the laser at an individual's eyes. o Enclose as much of the beam path as possible. o Place beam stops at the end of the useful beam path. o Locate the plane of the laser beam and associated optical devices well above or below the eye level of observers sitting or standing positions. o Firmly mount the laser to ensure the beam does not stray from the intended path. o Use proper eye protection if eye exposure to the direct beam or a specular reflection is possible. o Remove all unnecessary reflective surfaces from the area of the beam path.
Class 3B	These lasers are medium power lasers that have an output power between 5 mW and 500 mW. They may be hazardous under direct and specular reflection viewing conditions; however, they normally do not present a fire hazard, diffuse reflection hazard, nor a laser generated air contaminant (LGAC) production hazard. Protective eyewear is required when working with Class 3B. *Precautions:* o Operate the laser only in a Laser Controlled Area. o Permit only properly trained and authorized personnel to operate the laser. o Do not allow access to unauthorized personnel and control spectators/visitors. o Display a warning light or buzzer at the entrance of the Laser Controlled Area to indicate when the laser is in operation. o Display a warning sign at the entrance of the Laser Controlled Area. o Do not aim the laser at an individual's eyes. o Enclose as much of the beam path as possible. o Place beam stops at the end of the useful beam path. o Locate the plane of the laser beam and associated optical devices well above or below the eye level of observers sitting or standing positions. o Firmly mount the laser to ensure the beam does not stray from the intended path o Provide and ensure use of proper eye protection for everyone within the Laser Controlled Area. o Do not view the beam or its specular reflection with collecting optics without sufficient eye protection. o Remove all unnecessary reflective surfaces from the area of the beam path.

Class 4	These lasers have an output power exceeding 500 mW. They are a hazard to the eyes and skin from the direct beam, They may also pose a fire hazard or diffuse reflection hazard, and may also produce laser generated air contaminants (LGAC) and hazardous collateral radiation (e.g. plasma, etc.). Protective eyewear is required when working with Class 4. *Precautions (additional to the one stated for Class 3B):* o Use appropriate shielding between personnel and any beam having sufficient irradiance to pose a skin or fire hazard. o Use remote viewing methods where feasible (video monitoring) to accomplish any necessary viewing of the beam. o Ensure all enclosure (e.g. enclosure box, curtains, etc.) are made from fire-resistant materials. o Construct beam stops of fire resistant material that create a diffuse reflection.

Laser manufacturers have been required to label the Class of their products since September 1985. If a laser is/was not manufactured or labeled in accordance with American, European, or acceptable international standards for laser classification, the laser might not be approved by the Laser Safety Officer (LSO) / Research Safety Team (RST). In addition, any modified commercial laser or new constructed laser in the laboratory must be classified and labelled as per the ANSI Standard. The Laser Safety Officer (LSO) can assist in determining the appropriate classification.

Additional Information

A summary table of the laser classes can also be found in this link. Please note that this table only applies to laser that emits in the visible part of the spectrum.

Document History

REV	DATE	PREPARED BY	DESCRIPTION
01	Apr. 2020	D. Darios	New document

Appendix F – Choosing Eye Protection

Protective eyewear with appropriate filtering optics can protect the eyes from direct, reflected, and/or scattered laser beams. These protection devices attenuate the intensity of laser light while transmitting enough ambient light for safe visibility (visible luminous transmission or VLT), see Figure 1. The ideal eyewear reduces light transmission of a specific wavelength, or range of wavelengths, to a safe level while maintaining adequate light transmission at all other wavelengths. Eyewear is generally selected based upon the Optical Density (O.D.) for the given wavelength(s) and power level and the degree of luminous transmission of the filter. Optical Density (OD) is a measure of the attenuation of energy passing through a filter. The higher the OD value, the higher the attenuation and the greater the protection level. OD is the logarithmic reciprocal of transmittance, expressed by the following:
$\boldsymbol{OD} = -\boldsymbol{log_{10}}(\boldsymbol{T})$, where T is transmittance.

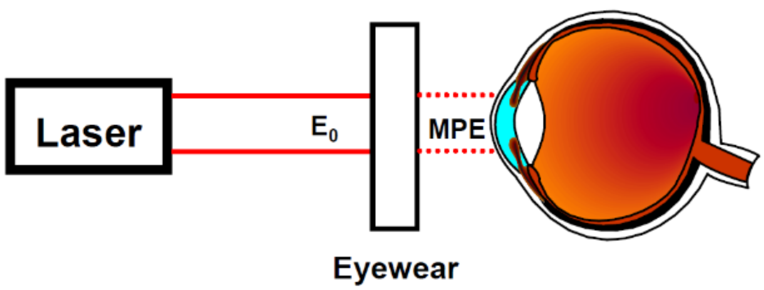


Figure 1. Laser protective eyewear attenuation mechanism.

Table 1. Relation between Optical Density, Transmission and Attenuation Factor.

OD (Optical Density)	Transmission in %	Attenuation Factor
0	100%	1
1	10%	10
2	1%	100
3	0.1%	1,000
4	0.01%	10,000
5	0.001%	100,000
6	0.0001%	1,000,000
7	0.00001%	10,000,000

While most protective eyewear offers protection over a range of wavelengths, not all of the wavelengths will be attenuated to the same extent. Therefore, when selecting eye protection it is important to ensure that the optical density of the eyewear is adequate for the wavelength or range of wavelengths of interest. In addition, eyewear should always be labeled with information regarding the wavelength(s) for which they provide protection and what the optical density is for each wavelength or range of wavelengths.

The other factor that is important in selecting protective eyewear is the damage threshold specified by the protective eyewear manufacturer. The damage threshold is the level of irradiance above which damage to the filter will occur from thermal effects after a specified period of time - usually 10 seconds.

Once the damage threshold is exceeded, the filter ceases to offer any protection from the laser radiation and serious injury can occur. The damage threshold varies with the type of material used in the filter.

Important factors in selecting appropriate eyewear are:

1) Laser power and /or pulse energy;
2) Wavelength(s) of laser output;
3) Potential for multi-wavelength operation;
4) Radiant exposure or irradiance levels for which protection (worst case) is required;
5) Exposure time criteria;
6) Maximum Permissible Exposure (MPE);
7) Optical Density requirement of eyewear filters at laser output wavelength;
8) Visible light transmission requirement and assessment of the effect of the eyewear on the ability to perform tasks while wearing the eyewear;
9) Need for side-shield protection and maximum peripheral vision requirement;
10) 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;
11) Need for prescription glasses;
12) Comfort and fit;
13) Degradation of filter media, such as photo bleaching;
14) Strength of materials (resistance to mechanical trauma and shock);
15) Capability of the front surface to produce a hazardous specular reflection;
16) Angular dependence of protection afforded;
17) Requirement for anti-fogging design or coatings.

Note: For very short pulses, studies have shown that protective filters can exhibit non-linear effects such as saturable absorption when the filter is exposed to pulses of ultra-short duration (i.e. $< 10^{-12}$ s). Therefore, the optical density of the filter may be considerably less than expected for very short pulses. In these cases, it is strongly recommended that the manufacturer is consulted when choosing protective eyewear for these types of lasers.

Full Protection vs Alignment Style Protection

Laser protective eyewear can either be full protection or alignment style. Full protection will block a direct or reflective strike from the laser source in question for a minimum duration of 10 seconds. Full protection shall be worn whenever possible and if dealing with solely invisible beams. Alignment eyewear is an option for use with visible beams and gives partial visibility, but not full protection from a direct or reflected strike.

The LSO or manufacturer can be consulted to assist in selecting the appropriate laser safety eyewear during the laser registration process.

Appendix G – Alignment Guidelines

The most likely time for a laser accident to occur is during alignment of laser beams. It is therefore very important to take appropriate precautions while performing this task and to ensure that the SOP has a section outlining the way in which laser alignments must be conducted.
The techniques for laser alignment listed below are to be used to help prevent accidents during alignment of a laser or laser system.

1. Pre-alignment recommendations

- Exclude unnecessary personnel from the laser area.
- Remove all reflective objects such as, watches, rings, dangling badges, necklaces, and reflective jewelry to reduce accidental reflections. Use of non-reflective tools should also be considered.
- Post a "Warning Notice" sign at entrances when temporary Laser Controlled Areas are set up (e.g. where the lasers are normally Class 1/enclosed lasers) or unusual conditions warrant that additional hazard information be available to personnel wishing to enter the area.
- Ensure that the individual conducting the alignment activities is authorized to do so by the PIs/Center Directors.
- It is recommended that at least two laser users are present during the alignment activities.
- Plan ahead to ensure that all equipment and materials needed are present prior to beginning the alignment.
- Remove all unnecessary equipment, tools, and combustible materials (if the risk of fire exists) to minimize the possibility of stray reflections and non-beam accidents.
- Have all beam location devices ready, e.g., sensor cards, viewers, etc.
- Review the SOP for alignment of the laser beam.

2. Alignment recommendations

- Wear laser protective eyewear during alignment (as indicated in the SOP), either with full protection for invisible beams or aligned for visible beams.
- Wear skin protection on face, hands and arms when aligning lasers emitting in the UV range (i.e. less than 400 nm).
- When aligning invisible (e.g. UV, IR) beams, use beam display devices such as image converter viewers or phosphor cards to locate the beams.
- If possible, use low-power visible lasers for path simulation of high power visible or invisible lasers.
- When aligning high-power lasers, use the lowest possible power level. Reduce beam power by using neutral-density filters, beam splitters, or dumps, or by reducing power at the power supply.
- Use a shutter or beam block to block high-power beams at their source except when actually needed during the alignment process. Make sure that the beam block is rated to terminate high power beams.

- Place beam blocks behind optics (e.g. turning mirrors) to terminate beam paths that might miss mirrors during the alignment process.
- Label areas where the beam path leaves the horizontal plane.
- Secure optics, optic mounts and beam blocks to the table as much as possible.
- If possible, locate and block all stray reflections before proceeding to the next optical component, unused beams as well as at the end of the alignment procedure.
- Use beam blocks and/or laser protective barriers where alignment beams could stray into areas with uninvolved personnel.
- Be sure all beams and reflections are properly terminated before switching back to high-power operation.

3. Post-alignment recommendations

- Normal laser-hazard controls must be restored when the alignment is completed. Controls include replacing all enclosures, covers, beam blocks, and barriers and checking affected interlocks for proper operation.
- Remove the "Warning Notice" sign.
- Let everyone know in the laboratory that alignment is completed and full power operation is set to start.

4. Additional suggestions

- To find the optimum point while adjusting an optical mount, first, intentionally overdial, then tune toward the optimum point. Pass it, intentionally, overdial on the other side, then move back onto the optimum point (making sure to truly find the optimum point).
- When performing a sensitive optimization, always release finger-touch pressure from the adjustment knob between each adjustment iteration.
- Whenever possible, mark the edge of all new optics using a pencil or a permanent fine marker, indicating at a minimum:
  - Reflective/polished surface using an arrow (e.g., >);
  - Coating parameters (e.g., AR.10 = UV, AR.14 = 532 nm, AR.16 = 800 nm);
  - Substrate details (e.g., FS, BK7, 0dur, etc.);
  - Other key details when needed/appropriate (e.g., s/n, PO#, ref#, etc).
- Avoid fingerprints (or clean immediately) on coated optics; acid from fingers permanently damages the coating when left on optics for an extended time.
- Always use a proper optic container to store optics, or, if not possible, wrap optics in lens tissues, or temporarily deposit the optics face down (on lens tissue layers) on a safe and clean flat surface (away from drop or damage risks).
- A good method to clean optics is first to use a canned air duster (or compressed and filtered air) to remove the dust. If the optics still need cleaning then the use of solvent and lens tissue is required. Acetone can be used to remove tough contamination such as finger prints but it usually leaves a milky film on the optics. Methanol is a softer solvent than acetone (i.e. cannot remove tough contamination) but leaves the optics cleaner. Therefore, a good solvent for optic cleaning consists of a mix of 60% acetone and 40% methanol. It is recommended that this mixture is kept

in a glass bottle and prepared fresh; if large bottles are used they can be kept for less than 6 months and if pipette bottles are used the mix should be prepared before every cleaning procedure.

- Wideband Ti:sapphire oscillators are very sensitive to dust, and therefore sensitive to cleaning as well. Periodically clean the cavity optics and the Ti:sapphire crystal (never let the oscillator performance drop by more than 10%).

5. Special alignment suggestions

5.1. Flash lamps and YAG high-energy 532 nm beams

- Always align beams at low power [one way is to detune the Q-switch (QSW)] timing versus flash lamp timing to reduce green power.
- Always verify the YAG beam profile prior to sending it to a Ti:sapphire crystal or other crystals. Hot spots will likely cause severe irreversible damage to the crystal lattice or the crystal coating. Performing a dummy test on sapphire crystals can be an inexpensive way to ensure integrity of the Ti:sapphire when it is being pumped.
- Practical temporary beam blocks for a YAG 10-Hz green beam are white packing foams, which diffuse the powerful green beams temporarily during specific and approved alignment procedures.
- Any black anodized metal surfaces used as beam blocks should be rough, not a shiny, flat black. White ceramic is the preferred permanent beam-block material for YAG energetic beams.
- Use of photographic "burn paper" or non-developed photo paper (black) can be used to visualize the beam quality. Make sure to put the paper into a clear plastic bag to avoid debris blasts and avoid overexposure (use of back burns sometimes helps) to maintain profile information content of the burn marks. Beware of laser reflections on the plastic bag.

5.2. YAG/YLF high-power 532/527 nm beams

- Wear approved alignment goggles, which allow a faint green beam to be visible.
- Avoid placing your finger in a focused high-power beam.
- High-power, high-repetition-rate beams will ablate/remove the black anodization of most beam blocks, leaving residues on nearby optics.

5.3. 800 nm ultrafast beams

- For an 800-nm compressed beam (at peak power), alignment using white bleached business cards (while wearing eyewear) allows the user to see the second harmonic generation (SHG) (blue color) beam on the card for alignment purposes.
- When aligning large-diameter beams that are compressed or very intense, use the SHG beam on a white business card to center the beam on alignment irises. Center the beam on the iris looking at the throughput beam (which is the symmetrically clipped SHG blue beam). When aligning small-diameter beams, use the IR viewer to look at the concentric beam around the hole of the iris, or use an orange card when looking at the throughput beam.
- Beware of the secondary lasing cavity caused by back reflections when introducing the reflective surface in a pumped amplifier with flat (not Brewster) Ti:sapphire crystals (this is valid for other

types of gain mediums). Always use the minimum possible number of mirrors required to realign an amplifier. Thin white ceramic plates are useful and safe for both low- and high-power beams.

5.4. For UV wavelengths (180 – 266 nm)

- Always wear gloves and long sleeves when aligning UV beams to prevent skin exposure, which could lead to skin cancer.
- Calcium fluoride (CaF_2) substrate for transmissive optics should be used to prevent red-fluorescence nonlinear absorption effects when used with high-energy, high-power UV beams. Red fluorescence ultimately leads to a permanent increase of optical transmission loss (which appears as a brownish color).
- For reflective optics, fused-silica substrate is known to reduce coating absorption. Aluminum-coated gratings, even when coated against oxidation, will degrade rapidly when used for UV high energy beams.

Remember: the lower the wavelength, the smaller the spot size for a given focal-length lens/optic. When looking at a beam profile on camera, ensure that all harmonics are filtered out.

5.5. Ultrafast optical-parametric-amplifier beams (166 nm – 20 µm)

- For NIR and IR beams, liquid-crystal paper (sold by Thorlabs, Inc., Edmund Optics, Inc., etc.) can be very helpful to detect the position of far-IR beams that are outside the range of conventional beam viewers.
- The harmonic components of the beam can be misleading, so be aware that you may not have a correct setup even if you think you do.