C10 Laser Safety Guidelines

1. Introduction

Laser equipment are widely used in a variety of research activities in the laboratories. The fields of use include biotechnology, photochemistry, material processing, applied physics, optometry, medical equipment, etc. Laser equipment can emit intense, monochromatic and coherent radiation of an intensity that may impose hazards to personnel within and around the laser. Amongst the various potential hazards, eye and skin exposure to the laser operators requires particular attention. The purpose of this document is to provide the laboratory personnel at the Science Park with basic information and general guidelines on safe operation of laser equipment.

2. Types of Laser

The word “Laser” is actually an acronym for Light Amplification by Simulation Emission of Radiation. In simple term, laser is a device that produces an intense, coherent and monochromatic beam of light by stimulating electronic or molecular transitions. It produces electromagnetic radiation at wavelengths extending from 100 nm in the ultra-violet, through the visible (400-700 nm), and the near infrared (700-1100 nm), to the far infrared (1400 nm-1mm). Thus, the light emitted can be either visible or invisible.

Lasers can be operated in different modes either in the form of a continuous beam (CW) or as a single pulse or a series of pulses. The power output of CW and pulsed lasers are usually expressed in terms of watts (W) and Joules (J) respectively. Various lasers with different types of lasing media are available for different applications. Some examples are indicated in the table below.

Type	Example
Gas	Argon (Ar), Carbon Dioxide (CO_2), Helium Neon (He-Ne), Krypton (Kr), Excimer
Liquid	Dye
Solid-State	Neodymium-YAG (Nd-YAG), Ruby
Semi-conductor (Diode)	Gallium Arsenide (GaAs), Indium Phosphorous (InP)

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3. Laser Classification

Laser equipment is classified by evaluating its potential to cause harm. Referring to the International Electrotechnical Commission Standard (IEC 60825-1) and American National Standard (ANSI Z136.1), laser classification is based on the ability of the primary beam to cause biological damage to eye or skin during intended use. The maximum accessible emission limit (AEL) permitted for a particular class of laser is defined.

It is a requirement of the laser manufacturer to provide the correct classification of a laser product. This classification is made on the basis of a combination of output power (s) and wavelength (s) of the accessible laser radiation over the full range of capability during operation at any time after manufacture. An instrument label is needed to affix to the laser by the manufacture which indicates the hazard class. A brief description of each class is given below:

a) Class 1

Lasers that are safe under reasonably foreseeable conditions of operation, either because of the inherently low emission of the laser itself, or because of its engineering design such that it is totally enclosed and human access to higher levels is not possible under normal operation.

b) Class 1M

Laser products emitting in the wavelength range of 302.5 to 4000 nm, whose total output is larger than that of Class 1 permitted laser. The very low power density of lasers do not pose a hazard in normal use. However, they may be hazardous to eyes if gathering optics are used with them.

c) Class 1C

Any laser product which is designed explicitly for contact application to the skin or tissue.

d) Class 2

Laser products limit to a maximum output power of 1 mW (Continuous Wave) and operate in the visible wavelength region (400-700 nm). This type of laser is relatively safe as natural aversion response (blink response) can protect from eye injury.

e) Class 2M

Laser products that only emit visible radiation in the wavelength ranging from 400 to 700 nm, whose total output is larger than that of Class 2 permitted laser.

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Their diverging beams or very low power density are safe for accidental viewing during normal use. However, they may be hazardous to eyes if gathering optics are used with them.

f) Class 3R

Laser product that emit in the wavelength ranging from 302.5 nm to 1 mm with maximum output power of 5 mW (Continuous Wave). This is considered safe with restricted beam viewing.

g) Class 3B

Laser products that have an output power of continuous wave not exceeding 0.5W. **Lasers are hazardous when direct viewing of laser beams.** Viewing diffuse reflections is normally safe.

h) Class 4

Laser products that have output power greater than 0.5W for continuous wave. Class 4 lasers are the most dangerous class of laser. Such lasers are capable of burning the skin, and can cause ruinous damage to the eyes as the results of direct, indirect or diffuse beam viewing. It can also constitute fire, chemical or electrical hazards. **The most stringent control measures need to be established for Class 4 laser.**

4. Laser Hazards

Hazards associated with laser can be divided into two main categories, beam hazards and non-beam hazards. Beam hazards are of course dangers arising from the laser light directly and their concern on exposed tissues, skin or eyes when not protected properly. Non-beam hazards include the danger of exposure to toxic and cryogenic materials, electrical shock and ionizing radiation, etc.

4.1 Eye and Skin Hazard

The hazard depends on a number of factors, including the wavelength of light it emits, the intensity of the beam and the exposure duration. The eye is more susceptible to injury due to the focusing capability on the retina. If a visible or near infra-red beam enters the eye, it may be focused on the retina to a minute spot with intensity raising by a factor up to 200000 times. The worst case of incident may cause blindness. The pigmentation, ulceration and scarring of the skin and damage of underlying organs may occur from extremely high power irradiation. Certain wavelengths of laser light in the ultra-violet region may cause adverse effects similarly produced by over-exposure to sunlight.

4.2 Electrical

Most high power laser systems require high voltage and current. The use of laser systems can present an electric shock hazard. This may occur from contact with exposed utility power utilization, device control or power supply conductors.

4.3 Physical

Cryogenic fluids such as liquid nitrogen are often used for cooling of lasers and detectors. These fluids can produce severe skin burns and should wear appropriate PPE such as face shield and thermal insulated gloves during handling (for details please refer to “Safe Handling of Cryogens” from HKSTP’s SHE Handbook). Adequate ventilation should be provided for reducing the risk of asphyxiation.

4.4 Chemical

Dye lasers use an organic dye as their lasing medium. These dyes can be toxic, carcinogenic or flammable. Adequate ventilation and suitable PPE should be available for handling.

Hazardous compressed gases such as fluorine, hydrogen chloride are often used in laser system. The gas cylinders should be stored in exhausted area secured to the wall and piped to the laser system using the appropriate regulators and fittings (for details please refer to “Safe Handling of Compressed Gas Cylinders” from HKSTP’s SHE Handbook).

Air contaminants may be generated when certain laser beams interact with matter. Laser generated air contaminants (LGAC) include metallic fumes and dust, metallic oxide fumes, chemical and gaseous vapors and biological fragments from human and animal tissues. Various measures should be performed such as exhaust ventilation, respiratory protection and isolation.

4.5 Fire and Explosion

Class 4 lasers pose a fire hazard especially if focusing optics are used. Wherever a component of a laser facility has the potential to be exposed to an incident beam, it should be made of flame retardant material. These include beam stops and enclosure. Operation of Class 4 lasers should be aware of the ability of unprotected wire insulation and plastic tube to catch on fire from intense reflected or scattered beams, particularly from lasers operating at invisible wavelengths.

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5. Laser Hazard Control Measures

Control measures are devised to reduce the possibility of exposure of the eye and skin to hazardous levels of laser radiation and to other associated hazards during operation and maintenance of laser equipment. Hazard control measures can be grouped into three general categories: Engineering, Administrative and Personal Protective Equipment. Maximum emphasis should be placed on engineering control and, Class 3B and Class 4 lasers.

5.1 Engineering Controls

The controls include built-in safety features supplied by the manufacturers as well as the enclosure design and laboratory layout for accommodation of laser equipment.

a) Protective Housing – Required for all classes of lasers to limit access to associated laser beam and to electrical hazards associated with components and terminals. Interlock is required to install for Class 3B and Class 4 lasers to protect personnel from accidental exposure to the beam while the protective housing is opened.

b) Key Control – Class 3B and 4 laser systems should be provided with a master switch operated by a key, or by coded access (such as computer code). The authority for access to the master switch shall be vested.

c) Beam stop or Attenuator – The inadvertent exposure shall be prevented by the use of permanently attached beam attenuator, filter or beam stop on viewing portals and display screen. A beam attenuator can reduce the output of a laser beam to a level at or less than maximum permitted exposure levels (MPE). Consideration must be given to the material selection of the beam stop to reduce the risk of fire or burn.

d) Remote Interlock Connector – A remote interlock connector allows connection to an emergency master disconnect interlock or to a room, entrance, floor or area interlock. Safety latches or interlocks are used to deactivate the laser in the event of an unexpected entry into laser controlled areas. The design of interlocks must allow both rapid egress and admittance by personnel in emergency situation.

e) Activation Warning System – It consists of audible sound, warning lights or verbal “countdown’ which notifies personnel that the laser is being activated. A red light is usually connected to the interlock system and typically mounted near the entry points to the controlled area.

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f) Beam Paths – The beam path consideration is given to direct, reflected and scattered radiation in the establishment of boundaries of the laser controlled area (Nominal Hazard Zone) as furnished by the manufacturer. The direct beam path should be kept above or below eye level.

g) Laboratory Design – A laser laboratory, in particular with the operation of Class 3B or 4 lasers, should be isolated from all other activities not directly related to laser works. Windows should be kept to a minimum and need to be covered by laser curtain with fire retardant material capable of withstanding a direct continuous hit form high power laser beams. Walls, ceilings and fitting should be painted with a light colored matt paint to enhance illumination and minimize specular reflection. There should be adequate ventilation especially if cryogens are used for cooling detectors or if toxic fumes are produced.

5.2 Administrative Controls

Administrative control covers comprehensive laser safety program including writing up procedures for beam alignment and operation, stipulating training to laser operators, providing adequate label and warning signs on laser equipment and designated laser area, setting up policy for access control on laser laboratory and developing an emergency plan.

a) Standard Operating Procedures (SOP) – SOP shall be written and approved for Class 3B and 4 lasers. SOP is usually a concise document that provides general safety guidelines and control measures, hazard information, training requirements and emergency procedures, etc. Laser operators must be familiar with the procedures prior to laser operation and beam alignment. A copy of the procedure should be posted on the laser laboratory.

b) Training – Training must be provided to personnel who operates Class 3B or 4 laser system. The purpose is to let laser operators get familiar with the hazards, control methods for the whole system, PPE requirement, signage meaning and safety procedures.

c) Laser Equipment Label – All lasers require labeling except class one which are deemed safe within normal operation conditions. Labels should comply with international standards such as IEC 60825-1, BS EN 60825-1, and ANSI Z136.1. The labels shall be permanently fixed, legible and clearly visible during operation, maintenance or service. The labeling system should contain hazard label and explanatory label showing the laser class, safety instruction, maximum output, pulse duration (if appropriate), emitted wavelength, name and publication date of standard.

Examples of labeling are shown as follows:

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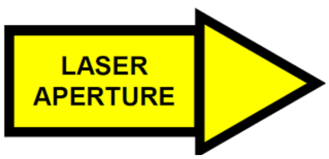
Hazard Label	Explanatory Label
	

For Class 3R, Class 3B and Class 4 laser products, labels bearing the wording 'LASER APERTURE' or 'AVOID EXPOSURE – LASER RADIATION IS EMITTED FROM THIS APERTURE' shall be displayed close to where the beams are emitted. Example of this aperture label is shown as follows:



d) Warning Label on Designated Area – The points of access to areas in which Class 3B, Class 4 laser and open beam work with modified Class 1M, Class 2M or Class 3R are used should be marked with appropriate warning labels. Appropriate label should contain cautionary or danger statement or protective actions. Some examples are shown as follows:

e) Control of Access – Lasers of Class 3B and 4 must be operated and maintained by authorized personnel. A list of operating personnel must be maintained and is highly recommended to be posted on the area. Access to the area should be restricted to only personnel working with the laser systems. All other personnel must not be allowed to enter the area while the lasers are switch on. The entry point must be well marked with appropriate signage with examples shown below:

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f) Emergency Plan – An emergency plan should be written down for any incidents which may occur such as laser eye strike, skin injury, critical equipment breakdown or chemical exposure. The emergency procedures and contact details must be provided and posted on the laser laboratory.

5.3 Personal Protective Equipment

a) Eye Protection

Safety eyewear is the most common and certainly the most important aspects of personal laser protection. It should be regarded as a last line of defense against exposure to laser radiation but not a convenient alternative to avoiding any engineering and administrative controls.

Laser safety eyewear is afforded by incorporating optical filter to reduce light transmission of a specific wavelength, or range of wavelengths, to a safe level while maintaining adequate light transmission at all other wavelengths. The Optical Density (OD) of a filter is a measure of this attenuation. The required OD, which is the logarithm of the ratio of maximum reasonably foreseeable exposure to Maximum Permissible Exposure (MPE), needs to be determined. Eyewear providing a smaller level of OD than required will not offer sufficient protection.

All eyewear supplied must provide adequate attenuation at the appropriate wavelength and comply with the international standards such as BS EN 207 (for full protection – 180 nm to 1 mm) and BS EN 208 (for alignment work – 400 nm to 700 nm). Eyewear must be clearly labeled with the OD, wavelength and laser emission type so that the user can identify the protection level for the laser they intend to use.

Appropriate safety eyewear must be worn for each particular laser operation. The supplier of eyewear can assist the users to choose appropriate eyewear when they know the laser model. The most important information for supplier's consideration include laser wavelength, maximum average power, smallest beam diameter and divergence, repetition rate for pulsed laser, maximum pulse energy and pulse duration.

The eyewear should be stored in designated, clean drawers or containers, in an area outside the hazard zone close to the entry point of laser laboratory. Periodic inspections must be made of safety eyewear to ensure there is no scratches, cracking or bleaching found.

b) Skin Protection

Skin protection may be required for laser operated in ultraviolet region such as excimer laser application. Leather gloves, leather aprons and jackets are generally considered the most desirable in protection against UV exposure.

6. General Safety Practices

Laboratory personnel shall adopt the following safety practices during operation of laser in the laboratories:

a) Ensure you well understand and strictly follow the SOP of the laser equipment to be operated.
b) Wear appropriate laser safety eyewear and other PPE as required. Inspect for any damage and wear of eyewear before use.
c) The activation warning light must be switched on to remind other personnel that laser is in operation.
d) Restrict unauthorized personnel to enter the laser laboratory.
e) Remove all watches, rings, bracelets, earrings and ID badges. These items can reflect light which can be hazardous.
f) Activate the local exhaust ventilation system if the laser operation is liable to generate air contaminants.
g) Verify that all safety devices are in place before energizing a laser.
h) Work with sufficient levels of room illumination.
i) Confine the beam within a well-defined area such as an optical table.
j) Keep the laser beam path as short as possible and enclose it as much as possible.
k) Never view the source of laser beam directly and no part of skin should be exposed to the direct beam.
l) Collimating instrument such as telescope or microscope should not be used to view the beam directly.
m) The laser should not be fired unless it is correctly aimed at the target area.
n) The laser should be switch off immediately and be kept under lock after use.

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o) Maintenance and repair work on laser systems should be performed only by certified personnel.

p) The use and storage of flammable chemicals should be avoided in the designated areas with Class 3B and 4 lasers. Appropriate firefighting equipment should also be available in the vicinity.

7. Emergency

Laboratory Persons In-Charge should address the potential hazards of individual laser equipment and corresponding safety measures to all concerned laboratory personnel. Suitable preparedness and arrangements should be in place to ensure that all laboratory personnel take appropriate actions in case of emergency.

In the event of an accident or incident involving suspected injury to the eye or skin, stop the experiment and turn off the laser equipment immediately. Report the accident or incident to the supervisor / Laboratory Person In-Charge and HKSTP following the "General Laboratory Emergency Procedures" in HKSTP's SHE Handbook. Seek medical assistance as soon as possible.