CALIFORNIA STATE UNIVERSITY
Stanislaus
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Laser Safety Program

Per Federal Regulation 21 CFR 1040,
California Code of Regulations Title 8
Section 3203 and
ANSI Z136.1

PLAN REVIEW

Complete this sheet each time the Laser Safety Program is reviewed and modified. The Director for Safety & Risk Management is responsible for reviewing and approving this plan as needed.

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1.0 Introduction

Lasers are devices that produce radiant energy by stimulated emission of light. Laser radiation is highly monochromatic, directional and coherent and can produce a beam of energy in the ultraviolet, visible, near infrared and far infrared regions of the electromagnetic spectrum. These beams pose unique and profound radiation hazards. As a consequence, laser usage must be carefully monitored to protect the health and safety of personnel and property.

Safety and Risk Management (S&RM) recognizes that few science labs use laser equipment. With this in mind, Environmental Health and Safety (EH&S) has prepared the Laser Safety program as a guideline to promote safe laser operations at Stanislaus State University.

Purpose

The purpose of this program is to increase the necessary awareness of safe laser use in the Stanislaus State academic environment. It provides a view of the hazards associated with laser use, controls, and procedures by which problems can be prevented and specifies national laser use standards where compliance is required when working with lasers. This program provides Stanislaus State campus laser workers in research, education and training with guidance in the requirements and recommendations for laser safety that are specified in the American National Standards Institute (ANSI) Standards Z136.1.

The broad basic components of this program include:

- Responsibilities of laser users
- Classification of lasers
- Risks posed by lasers
- Controls and risk prevention
- Emergency procedure

2.0 Scope and Responsibilities

2.1 Scope

S&RM updates the safety program and oversees campus laser operations. The Laser Safety Officer (LSO) is responsible for the implementation of safety Standards and compliance with this program.
This program includes laws and regulations regarding laser usage that are outlined in California Division of Occupational Safety and Health (Cal/OSHA) regulations, in the ANSI Standards handbook and in University policies and programs that must be followed when operating lasers devices on the Stanislaus State campus.

2.2 Responsibilities

Overview

In the most basic terms, each user is responsible to perform and manage laser operations in a manner that prevents unsafe laser use. In order to perform a task that involve operating lasers, each worker must:

- Undergo training for specific equipment and labs
- Read and know safe operating procedures
- Respect and utilize administrative and engineering controls
- Always utilize appropriate personal protective equipment

This allows laser safety to be exercised in a consistent and standardized way. Applying this same basic standard to workers around you and the labs in which you work will support safe laser operations at Stanislaus State.

2.3 Personal, PI and Laser Operator Responsibilities
Program requirements and recommendations target the individual user, who has a primary responsibility to ensure personal safety in operational labs. However, the Principal Investigator (PI) is the responsible party within the lab for requiring laser training, defining lab operational requirements, authorizing the purchase of safety equipment and maintaining safe lab operations.

The premise of personal safety extends into the awareness of environmental safety (i.e. the safety of the specific lab and of those working with and around the individual). When you work, you should be asking yourself questions such as 'Am I working safely?' and 'Would I be working that way?' Self-evaluation is one method by which we can focus on safe and efficient performance when using lasers. Statistically, most laser incidents are the result of operator error; personal awareness and responsibility are fundamental elements in avoiding laser incidents of all types.

As part of the laser user community, it is your obligation to correct or report unsafe actions or incidents. Actions and incidents may be performed by you, observed by you or known to you that could impact campus laser operations. It is unacceptable to participate in any situation that may result in injury, damage, loss or harm to the individual, community or organization.

Laser Operators are responsible for the safe operation of laser equipment, protection of themselves, workers in the vicinity, laser equipment, and lab facilities.
Before working with a Class 3 or Class 4 lab laser or laser system, operators must:

1. Read the Laser Safety Program.
2. Complete:
    - Initial laser safety training and refresher laser safety training every two years
    - Equipment- and lab-specific operational instruction
3. Review:
    - Laboratory-specific laser standard operating procedure (SOP)
    - Equipment-specific operating guides and safety instructions furnished by the manufacturer
4. Observe all operating safety rules.
5. Properly use all proper personal protective equipment (PPE), such as protective eyewear and sunblock, and safety devices, such as beam viewers, interlocks, and beam stops.
6. Notify their supervisor immediately of potentially hazardous conditions, personal injury, or property damage.

It is *recommended* that operators obtain a laser eye examination before working with Class 3B or Class 4 lasers.

2.4 Principle Investigator (PI), Laboratory Manager, and Supervisor Responsibilities

- Development of a safe laser lab environment
- Development of documentation about lab equipment and procedures
- Training of all laser workers in the safe operation of laser equipment

- Approving personnel to operate lasers
- Providing adequate and appropriate Personal Protective Equipment
- Identifying and labeling all laser equipment
- Notifying LSO and S&RM in the event of laser incident, accident or injury

Before allowing the use of lasers, PI's, Laboratory Managers, or Supervisors must:

1. Read the Laser Safety Program.
2. Prepare written laser SOPs and provide, implement, and enforce safety recommendations and requirements prescribed by the Stanislaus State Laser Safety Program.
3. Provide hands-on laser training on specific equipment to each laser user. Training must include routine procedures for safe operation, alignment procedures, emergency procedures, safety requirements and limitations of use.
4. Supervise laser use and operations in the laboratory.
5. Classify and label all lasers within their lab.
6. Complete all laser registration forms when purchasing lasers and submit to the LSO.
7. Ensure that laser operators and users have completed Laser Safety Training and refresher training every two years. Document specialized training of all employees who work with and around Class 3B and Class 4 lasers.
8. Ensure that only qualified and authorized personnel are permitted to operate lasers. The PI determines the operational qualification of an employee from departmental or technical training or other acceptable learning experience.
9. Notify LSO and S&RM immediately in the event of incidents involving injury or suspected injury from laser beam exposure.

It is recommended that PI's, Laboratory Managers, or Supervisors have all personnel who are scheduled to work with Class 3B or Class 4 lasers obtain a laser eye examination before beginning use.

2.5 Laser Safety Officer Responsibilities

The laser safety officer (LSO) reports to S&RM and is responsible for laser safety program development, implementation and compliance. The LSO is the technical advisor regarding laser safety and regulatory affairs. Responsibilities include but are not limited to:

- Verify that laser safety training records are maintained for all laser operators
- Review and approve laser SOP
- Inform S&RM of any safety concerns associated with the use of lasers
- Perform hazard evaluations of laser use areas
- Verify laser classifications
- Specify control measures
- Perform and document inspections
- Recommend and approve protective equipment
- Investigate laser incidents
- Maintain records associated with laser safety program
- Provides laser hazard signs and labels

3.0 Work Practices Reference

For Class 3B and Class 4 lasers and laser systems, the following operational work practices must be met:

- WARNING SIGNS: Appropriate warning signs must be posted at each lab entryway. These specify the type and class of laser and special precautionary instructions
- TRAINING: The laser must be operated only by personnel who have been appropriately trained in laser safety and in the specific laser procedures to be performed. All laser operators must be authorized by the Principal Investigator to operate the laser and perform the work
- BEAM POSITIONING: Laser beams must always be positioned above or below the normal eye level of a standing or sitting person
- BEAM TERMINATION: The laser must have any potentially hazardous beam terminated in a beam stop of an appropriate material
- REFLECTIVE MATERIALS: The laser must have only diffusely reflecting materials in or near the beam path, where feasible. Avoid wearing metal jewelry (wristwatches in particular) while working with laser beams
- WEAR EYE PROTECTION: Eye protection must be worn when Class 3B or Class 4 lasers are operated in a manner that is possible to allow eyes to be exposed to hazardous levels of direct or reflected laser radiation
- ENGINEERING CONTROLS: Engineering controls (interlocks, beam stops, signs, activation warning systems, etc.) are the first line of defense against laser hazards and must always be utilized. Control measures must not be defeated unless the operator is following a specific Standards Operating Procedure
- SUPERVISION: The laser must be under the direct supervision of an individual knowledgeable in laser safety
- BEAM TRANSMISSION: Windows and doorways must be covered or restricted in a manner to reduce transmitted laser radiation below the Maximum Permissible Exposure
- OPTICAL DEVICES: Optical devices may concentrate the amount of laser light arriving at the eye. When using an optical viewing device, ensure that the viewer does not directly view the beam or specular reflection. Microscopes used in laser work must be supplied with an attenuation filter
- SPECTATOR ACCESS: Lasers must be located so that access by spectators is limited. It is best to exclude visitors from labs in which Class 3B and Class 4 lasers are in use
- ACTIVATED EQUIPMENT: An activated laser must not be left unattended without appropriate safeguards such as illuminated warning signs, blackout curtains and door interlocks where applicable
- EQUIPMENT DISABLE: The laser or laser system should be disabled by means of a key when not in use, to prevent use by untrained operators
- ENTRYWAY CONTROLS: Class 4 lasers must have a system for entryway safety controls such as a doorway interlock mechanism
- EYE PROTECTION SUPPLIES: Personnel must be provided with appropriate eye protection in good operating condition. Protective eyewear must be manufactured and labeled for specific laser use, compatible with laser wavelengths, marked with appropriate the Optical Density and wavelength(s) and must pass enough visible light so that experiments can be conducted safely
- SECURE EQUIPMENT: Properly secure lasers and optical components used with them to the table to avoid eye injuries due to inadvertent movement of the items during experiments

- VIEWING BEAM: Never stare directly into a laser beam, regardless of class, even if eye protection is worn. Use an indirect means (beam card, photodetector, etc.) to observe the beam
- LIGHT SOURCE SHIELD: A shield should be provided around light sources used to pump lasers to prevent injury from flying glass in the event of a light source explosion.
- POWER SUPPLY: When accessing the power supply or other high voltage electrical equipment always utilize the buddy system. Personnel assisting with repairing, maintaining or replacing this equipment should be trained in cardiopulmonary resuscitation (CPR)
- NON-BEAM HAZARDS: Pay sufficient attention to non-beam hazards to prevent resulting injuries and illnesses

4.0 Laser Light

In Laser Labs, we are more concerned with the wavelength and power of the light that is emitted from a laser (the beam) than we are about how it is created. The type of laser is important in determining what associated hazards there might be, but ultimately, if there is an exposed beam, a potential hazard exists.

Why is Laser Light Harmful?
Laser light is created by STIMULATED PHOTON EMISSION (LASER is an acronym for *Light Amplification by Stimulated Emission of Radiation*).
Unlike normal light (produced by spontaneous photon emission), the photons in laser light are:

- Monochromatic (i.e. photons all have substantially one wavelength)
- Directional (i.e. photons all travel in the same direction)
- Coherent (i.e. photons are all in the same phase)

The characteristics of laser light allow for:

- Low divergence, so the beam spreads or scatters very little and maintains intensity over long distances
- High irradiance, so the beam is very bright and can focus intense energy on a small area

Lasers:

- Are the brightest light sources known
- Can produce significant eye hazards at relatively low energy levels
- Can be concentrated to an even higher intensity when focused by a lens (such as eyeglasses)
- Can be operated in pulsed mode to further increase power output

Lasers light generates heat and extremely focused brilliant light that will typically produce an enormous biological impact on the eyes.

Lasers operate in the 200 nanometer (nm) – 10,000+ nm range, which extends well below and above the visible light spectrum (~ 400 nm – ~ 700 nm). Many lasers produce light that is invisible to the human eye; in the event of an exposure, the aversion response (blink reaction ~0.25 secs) provides no protection to the viewer.

5.0 Laser Classification

Lasers and laser systems are grouped according to their capacity to produce biological injury to the eye or skin and laser classifications are specified in the ANSI Z136.1- Standards. Laser classification is an indication of the beam hazard during normal operation and is defined by the hazard potential of the accessible beam.

The hazard classification of a laser or laser system is represented by a number/letter combination; the higher the classification number, generally the greater the hazard and the more precautions are required.

All manufacturers have been required to classify and label all lasers produced since August 1, 1976. Information on the label must include laser class, the maximum output power, the pulsed duration (if pulsed), and the laser medium or emitted wavelengths.

ANSI modified the Standards for laser classification in 2007; models purchased earlier may still display older classification numbers, which must be updated. The current laser classifications are Class 1, Class 1M, Class 2, Class 2M, Class 3R, Class 3B, and Class 4.

The following chart indicates the recent broad reclassification of lasers.

ANSI Laser Hazard Classes	
Old	**New**
I	1/1M
II	2/2M
IIa	2
IIIa	3R
IIIb	3B
IV	4

Lasers are generally classified and controlled according to the following criteria.

Class 1

Laser systems that cannot emit laser radiation levels greater than the Maximum Permissible Exposure (MPE) and are considered to be incapable of causing eye damage under normal operating or viewing conditions

- Maximum power output; a few microwatts
- Higher class lasers may be fully embedded in Class 1 devices to enclose the beam path. Such lasers require extreme caution if the beam enclosure is opened for any reason (maintenance, troubleshooting, repair, alignment, etc.)

Class 1M

Laser systems considered incapable of producing hazardous exposure conditions during normal operation unless the beam is viewed with optical instruments, such as eye-loupes (diverging beam) or telescopes (collimated beam)

Class 2 and Class 2M

Visible, low power laser systems considered incapable of causing eye damage unless they are viewed directly for an extended period (greater than 1000 secs) or with certain optical aids

- Emit light in the visible portion of the spectrum (400 nm – 700 nm)
- Maximum power output < 1mW
- Normal human aversion response will usually prevent exposure

Class 3R

Medium-power laser systems that may be hazardous under direct and reflected beam viewing conditions, but do not pose a diffuse reflection or fire hazard. These are generally not hazardous if viewed for only momentary periods with the unprotected eye.

- Maximum power output 1 mW ≤ 5 mW
- Generally no eye damage with short duration exposure < 0.25 sec. (blink response)
- Visible and invisible (UV, IR) wavelengths
- Dangerous if viewed with magnifying optics (including eyeglasses)

Class 3B

Higher-power laser systems capable of producing a hazard from direct and reflected beams but rarely from diffusely reflecting surfaces (e.g. painted walls, white paper, etc.)

- Maximum power output 5 mW - 500 mW
- Aversion response is no protection
- Visible and invisible (UV, IR) wavelengths
- May be pulsed; potentially lethal high voltage supply

Class 4

High-power laser systems always capable of producing a hazard to the eye or skin

- Maximum power output > 500 mW
- Direct, Specular and Diffuse Reflection can cause severe eye and skin damage
- Aversion response is no protection
- Fire hazard; may be pulsed; potentially lethal high voltage supply

6.0 Laser Hazards and Injuries

Biological effects associated with lasers can be separated into two categories.

- BEAM-RELATED HAZARDS (occurring as a direct result of worker/beam interaction), which are typically caused by LIGHT AND HEAT
- NON-BEAM HAZARDS (caused as a result of indirect beam/target interaction or as a direct result of the properties of laser equipment). Hazards are not limited to the following, but these are key areas for consideration;
  - Electrical shock and fire hazards
  - Explosion and fire from compressed gases and solvents
  - Carcinogenic properties of laser dyes
  - Contaminants generated from a plume

– Collateral and plasma radiation

Biological effects may be;

- Acute - involving substantial exposure over a short period of time (burns)
- Chronic – involving low exposures over a long period of time (cancer)

6.1 Beam-Related Hazards

EYE INJURY

The most common injuries relate to eyes; the output of lasers is light and the eye is the organ that is most sensitive to light. Laser-produced eye injuries tend to be acute and catastrophic; all laser eye injuries are preventable.

Types of damage that eye hazards can cause are:

- Photochemical - light exposure triggering chemical reactions in tissue and breaking or forming molecular bonds. Photochemical damage occurs mostly with short-wavelength (blue) and ultra-violet light and can be accumulated over a period of time. Cataracts are an example of photochemical damage
- Thermal - the absorption of laser radiation causing a temperature rise in tissue to the point where denaturation of proteins occurs. Retinal burns are an example of thermal damage. A transient temperature increase of only 10 °C can destroy retinal photoreceptors
- Acoustic - A rapid rise in temperature may result in explosive boiling of vitreous humor causing mechanical shockwaves through tissues as the water evaporates to steam. The shock wave from the explosion can subsequently cause damage relatively far away from the point of impact. Hemorrhaging and bleeding are examples of acoustic damage that may be caused by exposure to pulsed lasers

The dependency factors for eye damage are:

- Length of exposure – power must be taken into account; a long continuous wave low-level exposure may do much less damage than a short-pulsed laser exposure
- Energy – the power of the source
- Wavelength – Determines which part of the eye absorbs the radiation and if radiation is focused by the eye onto the retina

Wavelength	Area of Damage	Pathological Effect
180-315 nm (Ultraviolet UV-B, UV-C)	Cornea - deep-ultraviolet light causes accumulating damage, even at very low powers	Photokeratitis (inflammation of the cornea, similar to sunburn)
315-400 nm (Ultraviolet UV-A)	Cornea and Lens	Photochemical cataract (clouding of the lens)
400 -780 nm (Visible)	Retina - Visible light is focused on the retina	Photochemical damage to the retina and retinal burns

780 -1400 nm (Near Infrared)	Retina - Near IR light is not absorbed by iris and is focused on the retina	Thermal damage to cataract and retinal burns
1400 -3000 nm (Infrared)	Cornea and Lens – IR light is absorbed by transparent parts of the eye before reaching the retina	Aqueous flare (protein in aqueous humor), cataract, corneal burn
3000 – 10000 nm (Far Infrared)	Cornea	Corneal burn

- Location of exposure – The macula and fovea provide for visual acuity and damage to these areas is likely to be catastrophic and permanent

Other Factors

When exposure occurs, the light range may not be visible and the brain may compensate for eye injury, leaving the worker unaware of any damage. Near IR radiation light, for example, is almost invisible to the human eye and because we don't see the light, our aversion response doesn't function.

Exposure to a high power Nd:YAG (Neodymium-doped yttrium aluminum garnet; Nd:$Y_3Al_5O_{12}$) laser emitting invisible 1064 nm radiation may be painless and victims may not immediately notice any vision damage. A pop or click sound from the eyeball may be the only indication that retinal damage has occurred (caused by the retina heating to over 100 °C resulting in localized explosive boiling accompanied by the immediate creation of a permanent blind spot). Multiple and compound injuries, such as cataracts, retinal burns, bleeding, blind spots and permanent loss of vision, can occur throughout the eye and at all wavelengths. Lasers with higher wavelengths generally pose greater risks.

Areas of the eye that are most vulnerable to damage are:

- Retina, the membrane lining the back of the eye that contains photoreceptor nerve cells which react to the presence and intensity of light
- Fovea, a 3-4% section of the retina in the center of the macula that provides for the most detailed and acute vision

RETINA

- The most important element of the eye
- Retina is 0.55 mm thick and easily damaged
- Contains the rods and cones, photoreceptors that are responsible for visual abilities such as day, night, color and peripheral vision and visual acuity
- Visible and near-IR laser light damage
  - Retinal sunburn may result from exposure to argon laser blue light (400 - 550 nm)
  - Retinal burns/detachment may occur in the Retinal Hazard Region (400 -1400 nm)
  - Laser strikes to the retina may create blind spots; repeated retinal burns can lead to blindness

FOVEA

- The majority of cones are situated in the fovea
- Acute vision may be lost instantaneously if a laser burn occurs in the fovea
- Near IR laser light is not absorbed strongly by the iris and focuses on the fovea

SKIN INJURY

Skin hazards occur at all wavelengths of laser light, although the impact is less dramatic than the hazards posed to eyes. Skin injuries tend to be chronic in nature.

The dependency factors for skin damage are:

- Time - thermal reactions usually cause tissue proteins to denature when exposure times exceed 10 microseconds
- Wavelength - laser light can be reflected or absorbed by various layers of skin
  - Most radiation is absorbed by the outer 4mm of the skin
  - 10,600 nm wavelengths (CO2, far infrared) are well absorbed by skin and cause surface burns
  - 1000 nm wavelengths (Nd-YAG) are not absorbed well by the skin and result in deep tissue burns similar to an electric burn

The types of biological injuries that can occur to the skin are:

- Skin burns –significant burns may occur from acute exposure to wavelengths of 300 – 10000 nm
- Skin Cancer – may be caused by chronic exposure to low levels or scatter radiation of UV-C at 200 – 280 nm. This light is not absorbed well by materials and may also cause erythema (sunburn) and accelerated skin aging

6.2 Non-Beam Hazards

The nature of non-beam hazards may be:

- Chemical
- Biological
- Physical
- Ergonomic

Typical non-beam biological hazards involve:

- Electrical (shock, fire)
- Gases, Solvents (explosions, fire)
- Dyes (toxicity, carcinogens)
- Plumes (biochemical dispersion)

In the research environment, users must be aware of electrical hazards from large power sources and power supply conductors operating at potentials in excess of 50 volts and electrical components such as capacitors, equipment grounding and exposed energized parts. There may be issues related to Laser Generated Air Contaminants (LGAC's) that can develop within the laser plume as a result of burning, vaporization or ablation of material.

The most prevalent hazards in the laser laboratory relate to the use of compressed gases, solvents, and dyes.

Compressed Gases may be:

- Simple Asphyxiants (dilutes or displaces the oxygen-containing atmosphere, leading to death by asphyxiation)
- Toxic with a low Threshold Limit Value (TLV), which is the amount of concentration in air of a substance permitted for a worker for a working lifetime without adverse health effects

Dye Lasers

- Fluorescent organic compounds form lasing medium, typically suspended in flammable solvents such as ethanol and methanol
- Process uses and produces both carcinogens and toxins. Powdered dyes are known carcinogens and must be handled with extreme care (use gloves and double bagging)
- Most dyes also exhibit unknown mutagenicity (DNA mutation) characteristics.

7.0 Controls and Prevention

To help maintain a safe laser environment, required and recommended controls in the ANSI Z136.1 Standards include:

- Engineering Controls – that address the physical environment in which the laser is operating
- Administrative Controls – that address operational requirements during laser use

Personal Protective Equipment (PPE) is an Administrative control that is NOT the primary means of protection. If PPE was the only method of protection and it failed, exposure would certainly result. PPE is always the backup for other Engineering and Administrative controls, but must never replace them or be used without them.

Laser use will always involve a combination of Engineering and Administrative controls. All administrative, procedural, and engineered safety control measures must be consistently applied when operating a laser laboratory. Required controls must not be ignored or defeated and recommended controls should always be seriously considered.

Based on a laser hazard evaluation that must be completed by the LSO, the LSO may approve controls that deviate from those listed in the ANSI Standards to obtain equivalent laser safety protection when specified engineered controls are not feasible or are inappropriate. Alternative controls and procedural substitutions may include:

- Specifically written Standards Operating Procedures
- Operating a Class 3B or 4 lasers with a fully open beam path
- Completely enclosing high power lasers to bring them to Class 1 specifications

Certain requirements apply to all laser use.

- All users must receive training and instruction, including
  - Laser safety training
  - Lab- / Equipment-specific operational training
  - Refresher training

- All lasers must have a protective housing (an enclosure surrounding the laser or laser system that limits access to electrical hazards associated with internal components and radiant energy. The useful beam emits from this protective housing)
- All lasers must be clearly labeled with the Class and type and an appropriate warning label

7.1 Engineered Controls

GENERAL

This section describes administrative, procedural and engineering measures which can reduce the chance of a laser-related incident. These measures should be considered when evaluating a class 3 or 4 laser facility. Although some items are appropriate for all facilities (e.g. posting proper warning signs), others may not be practical for some operations.

BEAM CONTROL

Enclose as much of the beam path as possible. If practical, the entire beam path should be enclosed. As a minimum, beam stops must be used to ensure no direct or specularly reflected laser light leaves the experiment area.

Laser beams should be limited to a horizontal plane which is well below or well above normal eye level. Securely fasten the laser and all optics on a level, firm, and stable surface.

REFLECTIONS

Remove unnecessary reflective items from the vicinity of the beam path. Do not wear reflective jewelry such as rings or watches while working near the beam path.

Be aware that lenses and other optical devices may reflect a portion of the beam from their front or rear surfaces. Avoid looking along or near the beam axis with unprotected eye. The probability of a hazardous specular reflection is greatest in this area.

POWER LEVEL

Operate a laser at the minimum power necessary for any operation. Beam shutters and filters can be used to reduce the beam power. Use a lower power laser when possible during alignment procedures.

SIGNS AND LABELS

The entrance to a class 3b or 4 laser facility must be posted with the appropriate warning sign. Each laser must be labeled as required by 21 CFR part 1040. These labels show the classification of the laser and identify the aperture(s) where the laser beam is emitted. Signs and labels may be obtained through the Laser Safety Office.

WARNING DEVICES

Class 4 laser facilities where the beam is not fully enclosed should have a visible warning device (e.g. a flashing red light) at the outside of the entrance which indicates when a laser is in operation.

CONTROL OF AREA
Except for fully enclosed and interlocked systems, an authorized user must be present or the room kept locked during laser operations.

INTERLOCKS
Many laser systems have interlocked protective housings which prevent access to high-voltage components or laser radiation levels higher than those accessible through the aperture. These interlocks should not be bypassed without the specific authorization of the Principal Investigator. Additional control measures must be taken to prevent exposure to the higher radiation levels or high voltage while the interlock is bypassed.

PERSONAL PROTECTIVE
Eye protection designed for the specific wavelength of laser EQUIPMENT light should be available and worn when there is a chance that the beam or a hazardous reflection could reach the eye. Protective eyewear should be marked by the manufacturer with the wavelength range over which protection is afforded and the minimum optical density within that range. Eyewear should be examined prior to each use and discarded if there is damage which could reduce its effectiveness. Protective eye wear generally will not provide adequate protection against viewing the direct beam of a high-powered laser. Wearing protective eyewear should not be used as an excuse for performing an unsafe procedure.

TRAINING
All operators must receive training in the safe and proper use of lasers by the PI (or a person designated by the PI) before being allowed to operate a laser.

OPERATING PROCEDURES
Written operating procedures must be available which include applicable safety measures.

MAINTENANCE/SERVICE
Maintenance, servicing, or repair of a laser should be performed only by a knowledgeable person who has been specifically authorized by the PI to perform such work. Whenever such work involves accessing an embedded laser of a higher class, the controls appropriate to the higher class must be applied. Any laser which is significantly modified must be reevaluated to determine its classification.

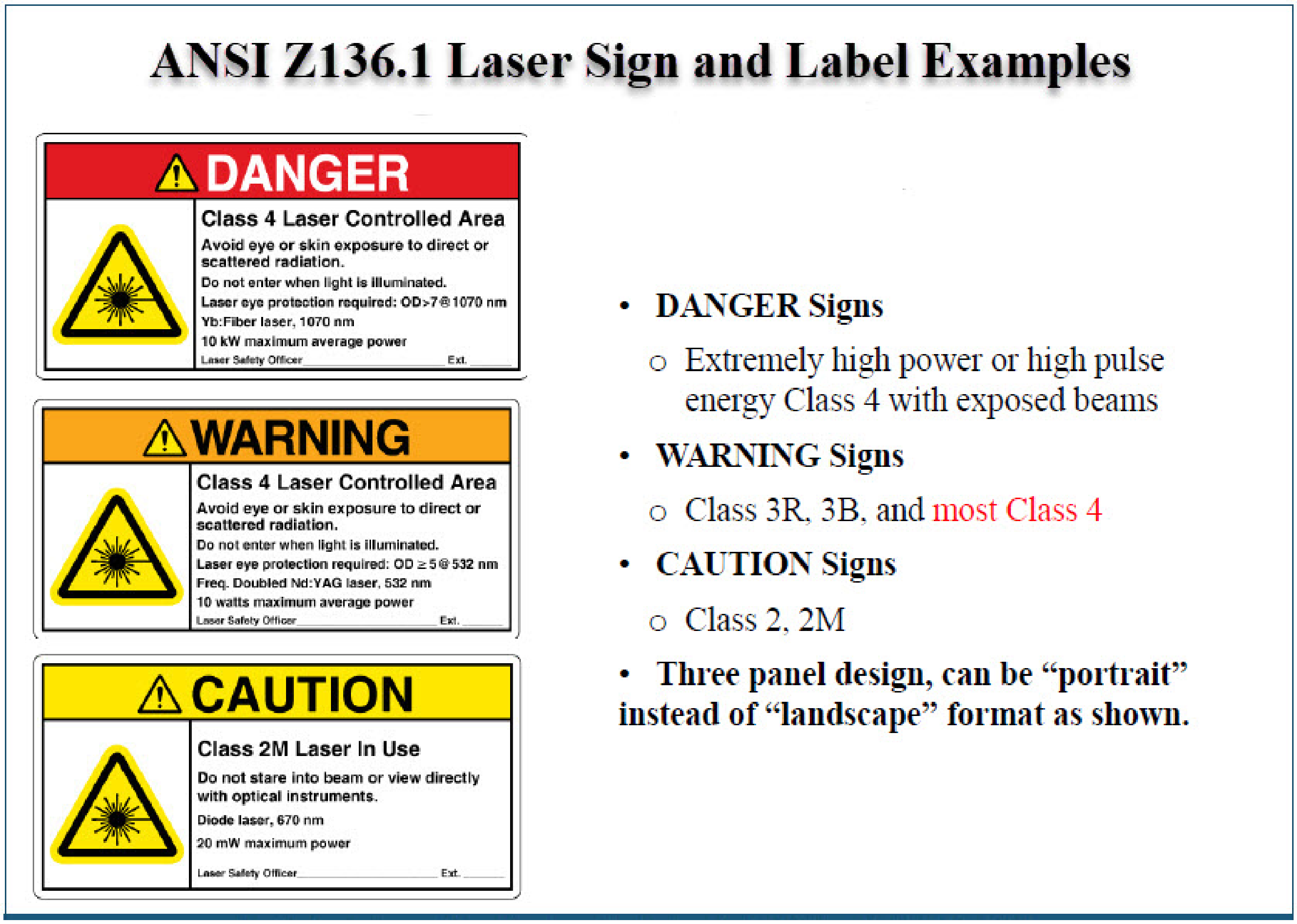
7.2 Administrative Controls
The LSO may apply alternate methods to achieve equivalent laser safety protection when some engineering controls are inappropriate. When necessary, these alternate methods may be administrative controls, including a written SOP. Each SOP is reviewed by the Laser Safety Office prior to being adopted. Unless otherwise specified, these requirements apply to Class 3B and Class 4 lasers.

Labels
Lasers must be labeled to indicate the class and type of laser. A laser classification label must be conspicuously affixed to the laser housing. The laser users must keep labels current and legible. Lasers

manufactured after August 1, 1976 must be classified and labeled by the manufacturer. It is the responsibility of the PI or lab supervisor to ensure that these labels are present.

Warning Signs

Class 2, 3 and 4 laser laboratories are required to have a **Laser Area Warning Sign** posted at each entrance to the laboratory at eye level. These signs are specific to the lab and laser system as shown in the examples below.



The following are the required information on laser signs according to ANSI Z136.1for different laser categories.

DANGER Signs

Extremely high power or high pulse energy Class 4 with exposed beams

AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION

WARNING Signs

Class 3R, 3B, and most Class 4

AVOID EYE OR SKIN EXPOSURE TO DIRECT OR SCATTERED RADIATION

CAUTION Signs

Class 2 and 2M laser system signs should include text similar to;

LASER RADIATION – DO NOT STARE INTO BEAM OR VIEW DIRECTELY WITH OPTICAL INSTRUMENTS

The LSO may allow alternate methods to achieve equivalent laser safety protection by administrative controls when engineering controls are inappropriate. This may be accomplished by specific SOPs where each SOP is reviewed and approved by the LSO prior to being adopted for use. These adjustments typically apply to Class 3B and Class 4 lasers.

Extra control measures

Laser purchase review must be conducted by EH&S prior to the purchase of a new laser or essential laser components. The purpose is to incorporate the new laser into the inventory system and to specify any special precautions or requirements for use.

- Authorized Access must be controlled for labs solely used for lasers or laser systems. Only personnel authorized by the PI or Lab manager are allowed access. Non laser-only labs must initiate precautions to prevent unauthorized access to laser areas.

7.3 Standards Operating Procedures

Written SOPs must constitute a comprehensive guide to the features, functions and use of laser equipment in the lab. SOPs must address beam and non-beam hazards and should be available for immediate reference. SOPs will include;

- Operating Procedures, Requirements and Restrictions for each device
- Hazard Information of each device and PPE requirements
- Alignment Procedures
- Personnel Access Limits while the laser is in use
- Medical Surveillance and Eye Examination Recommendations as applicable
- Outdoor Use and Demonstration requirements as applicable

7.4 Personal Protective Equipment (PPE)

Certain types of PPE are required when working with lasers. PPE is never a substitute for common sense and the use of good safety practices. Eye Protection is important and required because the eye is susceptible to serious damage from laser light. Protective eyewear can be goggles, face-shield or glasses and must be specifically suited to the wavelength and power of the laser in use. Before protective eyewear is used, it must be checked for defects and to verify it is suitable for the wavelengths of lasers in use. Damaged or unsuitable eyewear must be discarded and replaced.

Laser Protective Eyewear:

- Must be an appropriate safeguard, be available, in good condition and in sufficient quantities for all workers
- Is not the primary line of defense

- Is required to meet ANSI Z87.1 Standards for Class 3 and Class 4 lasers
- Must be marked with Optical Density and Wavelength
- Needs must be reassessed when new personnel, equipment or processes are introduced to the lab

Skin ProtectionBare skin may require cover to prevent acute exposure to high levels of laser radiation that may cause skin burns or chronic exposure to UV wavelengths (295 nm – 400 nm) that can result in sunburn, pigmentation change and skin cancer.

- Appropriate skin protection is required for Class 3B or 4 laser use. Skin protection can include gloves, lab coat, sun block, skin cream and possibly a face-shield

7.5 Beam Alignment

Alignment is the process that demands the greatest attention to safety because, according to the most recent figures:

- 73% of all reported laser injuries are eye-related
- 35% of eye-related injuries were associated with the alignment process
- 68% of eye-related injuries result in permanent injury

Because of excessive eye hazards during beam alignment, it must be performed in a manner that ensures that the eye is not exposed to light above the applicable MPE from the primary beam or specular or diffuse reflection of the beam. The group that normally uses the laser must write the alignment procedure, which must include the vendor (if alignment is performed by a qualified vendor) and the frequency of alignment.

When performing alignments, always:

- Review and follow written Alignment procedures
- Use Laser Alignment eyewear
  NEVER REMOVE SAFETY EYEWEAR DURING THE ALIGNMENT PROCESS
  If you cannot see the beam with the eyewear you are using, your eyewear is the wrong Optical Density. Turn off the laser and obtain eyewear with the correct Optical Density
- Use alignment aids
  - IR and UV cards that glow in the visible range
  - IR viewers

  DON'T LOWER THE LIGHTS TO SEE THE BEAM BETTER!!!
- Use the laser at reduced power or substitute low power lasers to trace and check the beam path
- Use beam blocks at each beam section to reduce potential for stray light
- Check for stray light before completing alignment and increasing power

8.0 Emergency Procedures

1. In the event of a laser incident that involves non-routine operating events Shut the laser off and remove the interlock key.

2. In the event of a fire:

- Alert everyone to exit the laboratory and be the last to leave
- Shout 'FIRE' loudly and frequently
- Turn on a fire alarm
- Do not try to fight the fire from inside the room; do it from a doorway so that you have a means of escape.

3. In the event of MAJOR injury call 911.

4. Obtain contact information from witnesses and/or personnel in the area as required.

5. Contact the PI and/or Lab Manager and describe the emergency.

6. The PI or the person in charge of the operation completes the incident report (https://www.csustan.edu/safety-risk-management/report-injury-illness-or-incident).

Appendix A: Laser Classification Table

Class1	Any laser or laser system containing a laser that cannot emit laser radiation at levels that are known to cause eye or skin injuring during normal operation. This does not apply to service periods requiring access to Class 1 enclosures containing higher-class lasers. **Maximum power output < 1 mW**
Class 1M	Considered incapable of producing hazardous exposure unless viewed with collecting optics. **Maximum power output < 1 mW**
Class 2	Visible lasers considered incapable of emitting laser radiation at levels that are known to cause skin or eye injury within the time period of the human eye aversion response (0.25 s). **Maximum power output < 1 mW**
Class 2M	Emits in the visible portion of the spectrum, and is potentially hazardous if viewed with collecting optics. **Maximum power output < 1 mW**
Class 3R	A laser system that is potentially hazardous under some direct and specular reflection viewing condition if the eye is appropriately focused and stable. **Maximum power output 1 mW ≤ 5 mW**
Class 3B	Medium-powered lasers (visible and invisible regions) that present a potential eye hazard for intrabeam (direct) or specular (mirror-like) conditions. Class 3B lasers do not present a diffuse (scatter) hazard or significant skin hazard except for higher powered 3B lasers operating at certain wavelength regions **Maximum power output 5 mW ≤ 500 mW**
Class 4	High-powered lasers (visible or invisible) considered to present potential acute hazard to the eye and skin for both intrabeam and diffused conditions. Also have potential hazard considerations for fire (ignition) and byproduct emissions from target or process materials. **Maximum power output > 500 mW**

Appendix B: Common Types of Lasers

Laser	Wavelength (μm)	Type	Mode
Argon (Ar)	0.488, 0.514, et.	gas	CW, P
Carbon Dioxide (CO_2)	9.6, 10.6	gas	CW, P
Copper Vapor (Cu)	0.510, 0.578	gas	CW, P
Gallium Arsenide (GaAs)	0.820 - 0.95	semiconductor	CW, P
Helium Cadmium (HeCd)	0.325, 0.441	gas	CW
Helium Neon (HeNe)	0.543, 0.594, 0.612, 0.633, 1.152, 3.390	gas	CW
Mercury Vapor (Hg)	0.48, 0.615, 1.530, 1.813	gas	CW
Neodymium YAG (Nd:YAG)	0.266, 0.532, 1.064, 1.33	solid	CW, P
Nitrogen (N_2)	0.869, 0.870, 0.889, 1.048, 1.231	gas	CW, P
Rhodamine 6G	0.570 - 0.650	liquid (dye)	CW, P
Ruby	0.694	solid	P
Ti :Sapphire	0.670	solid	CW, P
Water Vapor (H_2O)	27.974, 33.033	gas	CW
Xenon Chloride	0.308	gas	CW, P

CW = continuous wave laser (continuous output for a period of ≥ 0.25 seconds).

P = pulsed laser (laser which delivers its energy in the form of a single pulse, or a train of pulses, with the pulse duration < 0.25 seconds).

Appendix C: Laser Safety Inspection Checklist

PI / Instructor: ____ **Building & Room:** ________________________

	Inspected By: Date:	Y	N	NA	Comment
1	Are lasers classified appropriately (2, 2M, 3R, 3B, 4)?				
2	Are written SOP's in place?				
3	Are written alignment procedures available?				
4	Are written maintenance procedures available?				
5	Have all laser users attended appropriate training?				
6	Are all lasers labeled correctly?				
7	Have appropriate warning signs been posted at eye level at all entrances to the laser lab?				
8	If necessary, are illuminated warning signs in place?				
9	Is protective housings present and in good condition?				
10	Are there beam enclosures?				
11	Do surfaces minimize specular reflections?				
12	Is there any exposed wiring or circuits?				
13	Are windows and ports, which could allow a laser beam to stray into uncontrolled areas, covered or protected with non-reflective material during laser operation?				
14	Are beam stops present at the end of all beam paths? Are the non-combustible?				
15	Are barriers and screens non-combustible? Are there any burn holes?				
16	Is appropriate PPE available? Is it being used?				
17	Have laser users removed jewelry?				
	Class 3B and 4 Lasers				
18	Have all commercially produced Class 3B and Class 4 lasers, and all lasers made or modified on campus, been registered with the LSO?				
19	Do protective housing contain interlocks?				
20	Is spectator access limited?				
21	Has the nominal hazard zone been determined?				
	Class 4 Lasers				
22	Does the entry to the controlled area have fail safe interlocks?				
23	Are only authorized personnel permitted in laser lab?				
24	Does the laser have remote fire capability?				
	Check Prior to Laser Operation				
25	Is protective eyewear appropriate for laser operation?				
26	Is protective eyewear clean and free of damage?				
27	Are all beams traced and dumped?				
28	Are beam paths enclosed where possible?				
29	Is the optical bench free of unnecessary reflective items?				
30	If a beam crosses a walkway, are there posted barriers? Is a rope or chain placed across the path during laser operation?				

List and describe the corrective actions that were taken for any identified safety deficiencies.

Appendix D: Laser Pointer Safety
Most pen-sized laser pointers are battery powered and can cause eye damage if used improperly. The potential hazard is limited to looking directly into the laser beam with unprotected eyes. No hazard to the skin exists. Pen-sized laser pointers have become common presentation aids in recent years. These battery powered laser pointers produce a narrow bright red beam, are convenient to carry and use, are relatively inexpensive, and are readily available. Misuse of laser pointers, such as intentionally shining beams at individuals, is illegal.

The following guidelines for laser pointers must be followed:

- Laser pointers must be properly labeled with the appropriate laser hazard symbol. Pointers of > 0.5mW must also indicate the laser classification, maximum power output, and laser wavelength
- The manufacturer's safety instructions provided with the laser must be reviewed before using a laser pointer
- The owner of the laser pointer is responsible for its use
- Use of laser pointers should be limited to the intended purpose. Indiscriminate use may present an eye hazard
- The laser beam must never be intentionally directed toward oneself or directed toward another person. A person must never intentionally stare into the laser beam
- The laser pointer should be kept in a secure place and the beam should be turned off when not in use
- Mirror like surfaces (such as glass, metal, and other highly reflective materials) should be avoided when directing the laser beam
- Class 3R laser pointer use is prohibited when optically aided viewing of the beam is probable. Optical aids include telescopes, binoculars, viewing optics, and similar devices.
- Access to 3R laser pointers should be limited to responsible persons who have been informed of these guidelines by the owner or user

Appendix E: Personal Protective Equipment (PPE)

Certain types of PPE are required when working with lasers. It is important to note that the eye is susceptible to serious damage from lasers. Both continuous wave and pulsed lasers are potentially dangerous to the eye. Pulsed lasers are often more hazardous because they generate powerful bursts of laser radiation that can damage the eyes in a number of very serious ways. Before any protective eyewear is used, it must be checked for defects and to verify it is suitable for the wavelengths of lasers in use.

The following requirements must be met:

- Protective eyewear must be worn whenever Maximum Permissible Exposure (MPE) levels may be exceeded; however, it is good practice to always wear eye protection when lasers are in use
- Protective eyewear must be worn whenever Class 4 and 3B lasers are in use. Laser protective eyewear may include goggles, face shields, or prescription eyewear using special filter materials or reflective coatings to reduce the exposure to the eyes below the MPE
- Protective eyewear must fit and be comfortable to wear
- Protective eyewear must be approved by ANSI and clearly labeled with optical densities and wavelengths for which protection is afforded. Eye wear must be inspected periodically by the user for pitting and cracking of the attenuating material, and for mechanical integrity and light leaks in the frame
- Laser eye protection in the form of goggles should be provided for each laser control area. The goggles should be kept in a protected and easily accessible location. They must be available for laser operators and visitors to laser areas. Each set of goggles must be clearly marked for the laser that they accompany. Any visitor to the laser area is required to use appropriate goggles
- Eyewear provides protection over a narrow range of the laser spectrum. Eyewear designed for protection at one wavelength may afford little or no protection at another wavelength. Consult eyewear manufacturers for proper selection of protective eyewear
- Adequate skin protection must be provided to protect against acute exposure to high levels of laser radiation that may cause skin burns. This is especially true for chronic exposure to high levels of some UV wavelengths and may require face shields and garments that cover all bare skin.

Appendix F: Glossary

Absorption – Transformation of radiant energy to a different form of energy by interaction with matter

Aversion response – Closure of the eyelid, eye movement, papillary constriction, or movement of the head to avoid an exposure to a noxious or bright light stimulant. The aversion response to an exposure from a bright, visible, laser source is assumed to limit the exposure of a specific retinal area to a 0.25s or less.

Beam – A collection of light/photonic rays characterized by direction, diameter (or dimensions), and divergence (or convergence)

Coherent – A beam of light characterized by a fixed phase relationship (spatial coherence) or single wavelength, i.e. monochromatic (temporal coherence)

Collimated beam – Effectively, a "parallel" beam of light with very low divergence or convergence

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

Divergence – The increase in the diameter of the laser beam with the distance from the exit aperture, based on the full angle at the point where the irradiance (or radiant exposure for pulsed lasers) is $1/e$ times the maximum value

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

Infrared – The region of the electromagnetic spectrum between the long-wavelength extreme of the visible spectrum (about 0.7 μm) and the shortest microwaves (about 1mm)

Laser – A device that produces radiant energy predominantly by stimulated emission. Laser radiation may be highly coherent temporally, spatially, or both. An acronym for Light Amplification by Stimulated Emission of Radiation

Laser classification – An indication of the beam hazard level of a laser or laser system during normal operation or the determination thereof. The hazard level of a laser or laser system is represented by a number or a numbered capital letter. The laser classifications are Class 1, Class 1M, Class 2, Class 2M, Class 3R, Class 3B, and Class 4. In general, the potential beam hazard level increases in the same order.

Laser pointer – A laser product that is usually hand held that emits a low-divergence visible beam and is intended for designating specific objects or images during discussions, lectures or presentations, as well as for the aiming of firearms or other visual targeting practice. The products are normally Class 1, Class 2, or Class 3R.

Laser Safety Officer (LSO) – One who has authority and responsibility to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards

Laser system – An assembly of electrical, mechanical, and optical components which includes a laser

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.

The highest power or energy density (in W/cm^2 or J/cm^2) of a light source that is considered safe, i.e. that has a negligible probability for creating damage. It is usually about 10% of the dose that has a 50% chance of creating damage under worst-case conditions. The MPE is measured at the cornea of the human eye or at the skin, for a given wavelength and exposure time.

A calculation of the MPE for ocular exposure takes into account the various ways light can act upon the eye. For example, *deep-ultraviolet light* causes accumulating damage, even at very low powers. *Infrared light* with a wavelength longer than about 1400 nm is absorbed by the transparent parts of the eye before it reaches the retina, which means that the MPE for these wavelengths is higher than for visible light.

In addition to the wavelength and exposure time, the MPE takes into account the spatial distribution of the laser light. Collimated laser beams of *visible and near-infrared light* are especially dangerous at relatively low powers because the lens focuses the light onto a tiny spot on the retina. Light sources with a smaller degree of spatial coherence than a well-collimated laser beam lead to a distribution of the light over a larger area on the retina. For such sources, the MPE is higher than for collimated laser beams.

In the MPE calculation, the worst-case scenario is assumed, in which the eye lens focuses the light into the smallest possible spot size on the retina for the particular wavelength and the pupil is fully open. Although the MPE is specified as power or energy per unit surface, it is based on the power or energy that can pass through a fully open pupil ($0.39\ cm^2$) for visible and near-infrared wavelengths. This is relevant for laser beams that have a cross-section smaller than $0.39\ cm^2$.

Monochromatic light – Having or consisting of one color or wavelength.

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 appropriate MPE.

Optically aided viewing – Viewing with a telescope (binocular) or magnifying optic. Under certain circumstances, viewing with an optical aid can increase the hazard from a laser beam.

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.

Pulsed laser – A laser which delivers its energy in the form of a single pulse or a train of pulses. The duration of a pulse is less than 0.25 seconds.

Reflection – Deviation of radiation following incidence on a surface

Specular reflection – A mirror-like reflection

Telescope viewing – Viewing an object from a long distance with the aid of an optical system that increases the visual size of the image. The system (e.g. binoculars) generally collects light through a large aperture thus magnifying hazards from large-beam, collimated lasers.

Transmission – Passage of radiation through a medium

Threshold Limit Value (TLV) - TLVof a chemical substance is a concentration level to which it is believed a worker can be exposed day after day for a working lifetime without adverse health effects. The TLV is an estimate based on the known toxicity in humans or animals of a given chemical substance and the reliability & accuracy of the latest sampling and analytical methods.

TLV is defined as a concentration in air, typically for inhalation or skin exposure. Units are in parts per million parts of air (ppm) for gases and in milligrams per cubic meter (mg/m^3) for particulates such as dust, smoke and mist.

TLVs for physical agents include those for noise exposure, vibration, ionizing & non-ionizing radiation exposure and heat & cold stress.

Ultraviolet radiation – Electromagnetic radiation with wavelengths between 180 nm and 400 nm (shorter than those of visible radiation)

Visible radiation (light) – The term is used to describe electromagnetic radiation which can be detected by the human eye. This term is used to describe wavelengths which lie in the range of 400 nm to 700 nm. Derivative Standards may legitimately use 380 nm to 780 nm for the visible radiation range.

Wavelength – The distance in the line of advance of a sinusoidal wave from any one point to the next point of corresponding phase (e.g. the distance from one peak to the next)