UNIVERSITY OF ALBERTA
ENVIRONMENT, HEALTH & SAFETY

LASER SAFETY MANUAL

Department of Environment, Health & Safety
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A. Design and Operation

1. Laser Design

The word LASER is an acronym for "**L**ight **A**mplification by the **S**timulated **E**mission of **R**adiation" which describes how laser light is generated at the atomic level. To understand how this is accomplished, a general description of laser design is required.

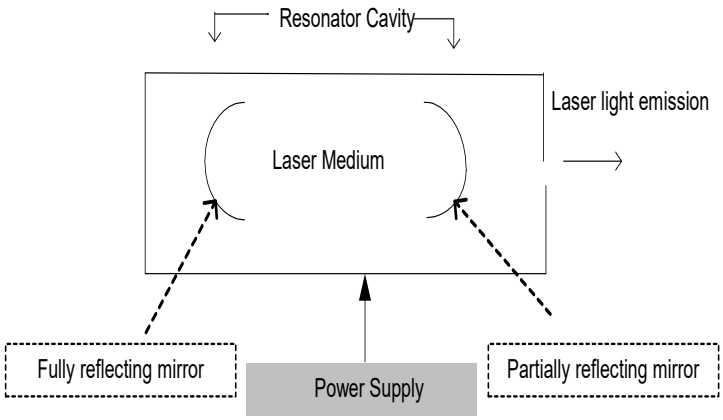
1.1 Ordinary light

Ordinary light, such as that from a light bulb - is produced when tungsten atoms are heated with an electric current causing the tungsten electrons to be "excited" to a higher energy level. The electrons loose their energy of excitation by releasing it in the form of photons of various wavelengths in the visible portion of the electromagnetic spectrum (i.e. white light). Since each excited electron releases its photon independently of the other excited electrons, the individual photons are released at different times and in different directions and the emitted light is released in all directions around the light source (*isotropic emission*).

1.2 Laser components

Laser light on the other hand is *coherent*, *unidirectional* and *mono-energetic* meaning that the photons are all released at the same time, in the same direction, and are of the same wavelength. Figure 1 shows the typical components of a laser:

Figure 1



The laser medium may be:

- solid state ex: Nd:YAG
- semi-conductor ex: GaAlAs
- liquid ex: dye solution
- gas ex: XeCl

The power supply may be:

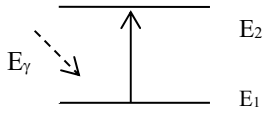
- flash or arc lamp - for solid state lasers
- electrical current - for semi-conductor and gas lasers
- another laser - for liquid laser

To understand how the laser emits mono-energetic, coherent, directional electromagnetic radiation, a discussion of atomic structure is necessary.

1.3 Laser light production

According to the Bohr Theory, the atom consists of a positively charged nucleus surrounded by negatively charged, orbital electrons. An electron's negative charge attracts it to the nucleus while its energy and angular momentum keep it in orbit around the nucleus. Each electron in a stable orbit has a discrete amount of energy referred to as its "ground state". When an electron absorbs energy from an external source its angular momentum increases and it moves further away from the nucleus. This event is referred to as an electronic transition to an "excited state" and is illustrated in figure 2.

Figure 2



To make a transition from the ground-state E_1 to the excited-state E_2, electrons can only absorb photons whose energy E_γ is equal to $E_2 - E_1$. In returning to the ground-state, electrons will re-emit a photon of energy E_γ.

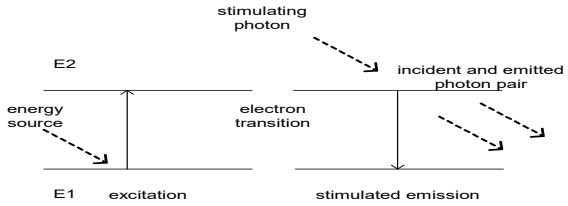
Electrons can return to the ground-state spontaneously or by collision with an incident photon of energy E_γ. The latter is referred to as "stimulated de-excitation". If the electron returns to the ground-state spontaneously, the resultant photon it releases will be emitted in a random direction as in the case of an ordinary light source. If on the other hand the electron returns to the ground-state by stimulated de-excitation, the photon it releases will be in phase (coherent) with the incident photon and have the same wavelength and direction of propagation. This is the case for a laser light source.

To make the rate of stimulated de-excitation which produces coherent laser light higher than the rate of absorption, a *population inversion* must be produced in the electronic structure of the atom. A population inversion is a condition in which electrons can accumulate in a meta-stable state which is an excited energy level in which spontaneous de-excitation is delayed.

In Figure 3, energy level E_2 is meta-stable and excited electrons accumulate there to produce a population inversion. The population inversion increases the probability that an incident photon of energy E_γ will cause stimulated de-excitation to occur in one of the excited atoms.

As seen on the right side of Figure 3, an electron in energy level E_2 is stimulated by the incident photon to make a transition to energy level E_1. In making the transition, the electron releases a photon of energy E_γ which has the same phase, energy and direction as the incident photon.

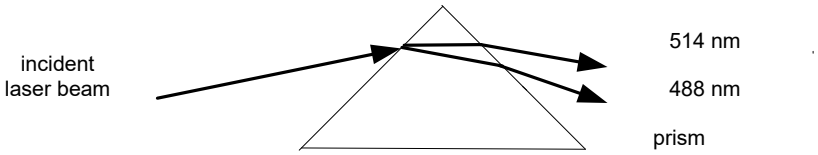
Figure 3



Both the emitted photon and original, incident photon can cause stimulated de-excitation of additional electrons during their transmission through the resonator cavity. By having reflecting mirrors at each end of the resonator cavity, the photons are reflected back and forth through the laser medium resulting in stimulated emission of even more photons and amplification of the photon intensity (see Figure 1). The mirror at one end of the resonance chamber is only partially reflecting and transmits a portion of the laser radiation. This portion is emitted through the laser output aperture for various applications.

The spectral output of a laser generally consist of a number of discrete wavelengths which can be spatially separated from one another by passing the light through a prism. As shown in Figure 4, light is refracted (bent) when it passes from a medium such as air to a different medium such as glass. If the incident light is composed of two discrete wavelengths, then several distinct beams will emerge from the prism since the shorter wavelength will have a larger angle of refraction.

Figure 4



In summary, an energy source such as an intense light source or electrical current can be used to excite electrons in a solid, liquid or gas. If the material contains atoms which have a meta-stable excited state, the excited electrons will accumulate in this excited state and can be stimulated to de-excite and emit a photon of the same wavelength, phase and direction as the stimulating photon - i.e. laser light.

2. Laser Operation

2.1 Modes of operation

A laser can have several modes of operation including:

- Continuous Wave (CW)
- Pulsed

A CW laser operates with a continuous output lasting 0.25 seconds or longer. The output time depends on the application and may range from seconds to hours.

A pulsed laser emits a pulse of energy lasting less than 0.25 seconds. Some lasers emit a train of pulses with a pulse repetition frequency up to hundreds of thousands of pulses per second.

2.2 Radiant energy and power

The radiant energy or power output of the laser determines its classification with respect to *ANSI Z136.1 - 2014, American National Standard for Safe Use of Lasers* and this standard has been adopted for regulatory purposes in Alberta and other provinces. The radiant energy of the laser is determined by the manufacturer and is expressed as joules (J) of output per pulse. For CW lasers the radiant energy is expressed as joules of output per unit time or watts ($1W = 1\ J\ s^{-1}$).

2.3 Radiant exposure and irradiance

Although the radiant energy and power are useful units for classifying the laser, it is the concentration of radiant energy or power in the beam that determines if the laser is a hazard for most exposure conditions. The concentration of radiant energy and power is expressed as joules cm^{-2} (*radiant exposure*) and watts cm^{-2} (*irradiance*) respectively.

Radiant exposure and irradiance are useful units for determining the hazard potential of the laser because biological damage is a function of the rate of energy absorption in a specific amount of tissue ($J\ s^{-1}\ g^{-1}$) and not simply the total energy absorbed. For example, if energy where absorbed slowly in a given mass of tissue the temperature rise in the exposed tissue would not be as great as it would be if the energy were absorbed quickly in the same mass of tissue. This is because the heat which is produced in the tissue is conducted into the surrounding tissue. If the rate of heat conduction is equal to the rate of energy absorption, the temperature of the tissue will remain constant and the tissue will not suffer any thermal damage.

The exception to this is exposure to UV radiation in which both photochemical and thermal damage can occur. While heat conduction away from the tissue may prevent thermal damage from occurring it will not prevent photochemical damage from occurring. Photochemical damage is a function of the total energy absorbed per mass of tissue ($J\ g^{-1}$) and not the rate of energy absorption. Photochemical damage is caused by the induction of chemical reactions in a cell due to absorption of ultraviolet light photons. Photons with wavelengths of 400 nm or greater do not have enough energy to cause photochemical reactions to take place and only thermal effects are important.

2.4 Beam shape

Although most lasers have a beam shape that is circular in cross-section, some laser beams have cross-sections that are rectangular or elliptical in shape. For circular beam lasers, irradiance is not necessarily uniform across the entire cross-sectional area of the beam. The power distribution may be Gaussian in shape or even truncated at the edges.

2.5 Beam divergence

Although a laser beam is directional, some divergence (beam spread) does occur. This results in an increase in the beam diameter as the distance from the exit port of the laser increases. Beam divergence is measured in milliradians (17.5 mrad = 1°) and lasers typically have a beam divergence of about 1 mrad. Therefore, at indoor distances there will not be a significant decrease in beam irradiance over the distance of travel.

2.6 Beam reflection

The portion of the beam that is not absorbed or transmitted is reflected off an object. Two types of reflections are important:

- Specular reflection
- Diffuse reflection

Specular reflections are mirror-like reflections in which the cross-sectional shape and intensity of the beam remain unchanged. Optical components such as mirrors and other shiny objects produce specular reflections at most wavelengths. In general, a specular reflection will occur when the wavelength of the laser is larger than the size of the irregularities in the surface of the reflecting object.

A diffuse reflection occurs when the irregularities on the surface of the object are randomly oriented and are larger than the wavelength of the laser light impinging upon it. The light is reflected in all directions from diffuse surfaces resulting in a significant decrease in the irradiance when viewed from any angle.

Specular reflections are much more hazardous than diffuse reflections. Eye or skin contact with a specular reflection is equivalent to contact with the direct beam therefore efforts must be made to eliminate unnecessary specular reflections of the laser beam. It should be noted that objects which appear rough and diffusely reflecting for visible light might produce specular reflections for longer wavelength infrared light.

2.7 Maximum permissible exposure

The maximum permissible exposure (MPE) is the level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin. ANSI Z136.1 - 2014 has several tables that list MPE values for the eye and skin based on wavelength and estimated exposure time. For example, the ocular (corneal) MPE for a frequency doubled, continuous wave, Nd:YAG laser which emits 532 nm light is 2.5 $mWcm^{-2}$ assuming a blink reflex time of 0.25 seconds. The skin MPE for this laser is 200 $mWcm^{-2}$. The ocular MPE for visible light is lower than the skin MPE in order to protect the retina from the increase in irradiance that occurs when light passes through the lens of the eye and is focused on the retina.

2.8 Nominal hazard zone

The nominal hazard zone (NHZ) is the space within which the level of direct, reflected or scattered laser light exceeds the MPE level for the laser. The NHZ is determined by first identifying all possible beam paths, both direct and reflected. The radiant exposure or irradiance is then calculated for each beam path and these values are compared to the eye and skin MPE values for the laser. Wherever the MPE is exceeded, that becomes part of the NHZ. Within the NHZ, personal protective equipment (e.g. laser goggles) must be worn. The NHZ must be determined by a person trained and qualified to perform the complex calculations which is usually the Laser Safety Officer.

3. Laser Classification

Lasers are classified based on their hazard potential which in turn is based on the radiant energy or power output of the laser. ANSI Z136.1 - 2014 specifies the following classes of lasers:

- **Class 1**: a laser incapable of producing damaging radiation levels
- **Class 1M**: a laser incapable of producing damaging radiation levels except with the use of optical viewing devices
- **Class 2**: a visible (400 -700 nm) laser which cannot exceed the MPE for ocular exposure times less than 0.25 s (i.e. accidental viewing)
- **Class 2M**: a visible (400 -700 nm) laser which cannot exceed the MPE for ocular exposure times less than 0.25 s (i.e. accidental viewing) except with the use of optical viewing devices

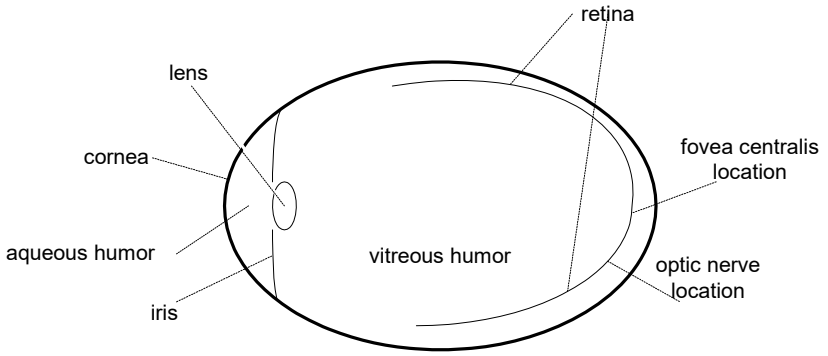
- **Class 3R**: a laser whose output will not exceed 5 times the ocular MPE
- **Class 3b**: a laser whose output exceeds 5 times the ocular MPE but which:
  (a) cannot exceed an average radiant power greater than 0.5 W for 0.25 s or longer or,
  (b) cannot produce radiant energy greater than 0.125 J for exposure times less than 0.25 s
- **Class 4**: a laser whose output exceeds the limits for Class 3b lasers

4. Biological Effects

4.1 Ocular effects

The biological effects of laser light on the eye depend on the wavelength of the laser light since light of different wavelengths differ in their ability to penetrate through the ocular components of the eye. Figure 5 shows the basic components of the eye.

Figure 5



eye

4.1.1 Ultraviolet light

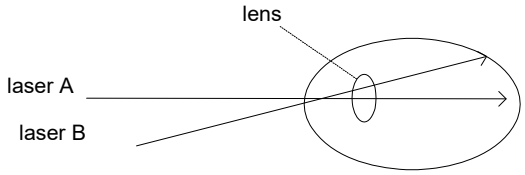
Ultraviolet light (100 - 400 nm) is weakly penetrating. UV-C (100 -280 nm) and UV-B (280 - 315 nm) are absorbed on the cornea and in the aqueous humor and cannot penetrate to the iris or lens of the eye. The principal hazard is photokeratitis (welder's flash) and erythema (reddening) which are reversible conditions if the damage is not too severe. UV-A (315 - 400 nm) can penetrate past the aqueous humor and absorb on the lens of the eye. The principle hazard is the formation of cataracts in the lens of the eye. UV-A cannot penetrate to the retina.

4.1.2 Visible light

Visible light (400 - 780 nm) is deeply penetrating and absorbs principally on the retina of the eye. In addition to this, the lens of the eye focuses images on the retina with an optical gain of approximately 100,000. This means that an external light source that produced an irradiance of 1 Wcm^{-2} on the cornea of the eye, would result in an irradiance of 100,000 Wcm^{-2} on the retina. Generally, an irradiance exceeding 10 Wcm^{-2} is enough to cause tissue damage. The type of damage to the retina depends on the location on the retina where the light source is focused. A light source focused on the peripheral part of the retina would be less serious than a light source focused on the *fovea centralis* (see figure 5) which is responsible for visual acuity. The most severe effects occur when laser light is focused on the optic nerve since damage to this area can lead to total blindness.

Figure 6 shows two laser sources, each focused on a different area of the retina. Light from laser A would lead to more damage since it is focused on the fovea centralis of the retina responsible for visual acuity, whereas light from laser B enters the lens at a different angle and is focused on the peripheral area of the retina where the tissue is less critical to vision.

Figure 6



4.1.3 Infrared light

Infrared light (780 nm - 1 mm) also has different penetrating ability depending on the wavelength. IR-A (780 - 1400) is a retinal hazard, similar to visible light. The difference is that IR-A can't be seen and could result in longer exposures since there would not be the aversion response (i.e. blink reflex) that there is to bright visible light. IR-B (1400 - 3,000 nm) does not penetrate past the lens but can cause cataracts. IR-C (3,000 nm - 1mm) absorbs principally on the cornea and can cause burns in this location if the irradiance is great enough.

4.2 Skin effects

The biological effects of laser light on skin include:

- thermal effects
- photochemical effects
- delayed effects

Thermal effects in skin occur when the rate of energy absorption exceeds the rate at which the tissue safely conducts heat away from the volume of tissue exposed. Experimental studies involving several cm^2 of skin exposed for 0.5 seconds with penetrating white-light (400 - 750 nm) have shown that a first degree burn to the skin (superficial reddening) can occur when the irradiance exceeds 12 Wcm^{-2} on the skin surface. A second degree burn (blistering) can occur when the irradiance exceeds 24 Wcm^{-2} and a third degree burn, involving complete destruction of the outer layer of skin (epidermis), can occur when the irradiance exceeds 34 Wcm^{-2}. However, the irradiance level that will result in damage depends on the total area of skin that is exposed since the rate of heat conduction at the centre of the exposed area will decrease as the total area of exposed skin increases.

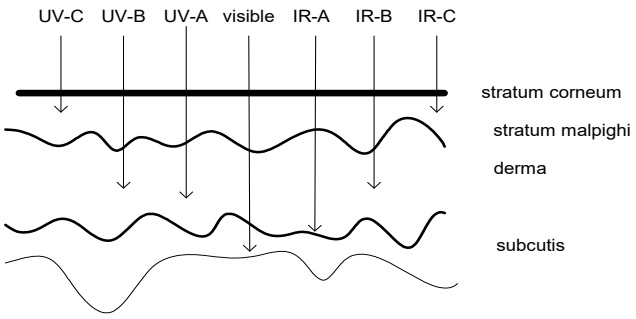
Photochemical effects such as sunburn are due to induced chemical reactions in tissue from the absorption of ultraviolet radiation. The degree of damage is related to the amount of energy absorbed in a given volume of tissue and is independent of the rate of heat absorption and conduction in the exposed area.

Delayed effects include skin cancer and accelerated skin aging. Skin cancer is due to the absorption of ultraviolet radiation which can cause mutations in the DNA of living cells. The probability of cancer is related to the total dose of radiation received whether the exposure is acute (short period) or chronic (long period).

The depth of penetration of radiation into the skin depends on its wavelength. Figure 7 shows how the depth of penetration changes at different wavelengths. It can be seen from this figure that UV-C and

IR-C radiation are initially absorbed in the outer, dead layers of skin (stratum corneum) however if the irradiance is high enough this layer will burn away exposing underlying layers to the laser radiation. UV-B and IR-B penetrate somewhat deeper into the layer of living skin tissue and can cause damage above certain thresholds. UV-B, because of its ability to penetrate to deeper tissue and induce photochemical reactions in the cells of this tissue, poses a risk of skin cancer that is not associated with other wavelengths. UV-A and IR-A penetrate even deeper into the skin and can cause damage by thermal effects. UV-A causes skin tanning and is also associated with accelerated aging of skin by modifying fibres that maintain skin resiliency. Visible light penetrates to the deepest layer of skin and its effects are entirely thermal in nature.

Figure 7



5. Laser Hazard Evaluation

5.1 Hazard factors

There are three factors which influence the degree of hazard of a laser:

- The laser's potential for causing injury
- Environmental factors
- Human factors

A laser's potential for causing injury depends on the emergent beam irradiance (Wcm^{-2}) and radiant exposure (Jcm^{-2}). If the maximum possible irradiance or radiant exposure for a particular laser exceeds the MPE then the laser is considered hazardous and control measures are required. In determining the maximum possible irradiance or radiant exposure for a particular laser it is assumed that all of the power or energy emitted by the laser is collected within an area defined by the limiting aperture of the eye. The limiting aperture of the eye depends on the wavelength of the laser light. For example, the limiting aperture for visible light is the area of a fully dilated pupil (0.385 cm^2). Therefore, a laser is considered to be hazardous if the following relationship exists:

1. *For continuous-wave and repetitively pulsed lasers:*

$$\frac{\text{Laser power output (W)}}{\text{Limiting aperture (cm}^2\text{)}} > \text{MPE (W cm}^{-2}\text{)}$$

2. *For single pulse lasers:*

$$\frac{\text{Laser energy output (J)}}{\text{Limiting aperture (cm}^2\text{)}} > \text{MPE (J cm}^{-2}\text{)}$$

The larger the margin by which the irradiance or radiant exposure of the laser exceeds the MPE, the greater the hazard of the laser and the greater the number of control measures required. As indicated in part A, section 3, lasers are grouped into 4 classes, with Class 4 being the most hazardous and having the largest number of required control measures. The classification of the laser is generally determined by the manufacturer, however in cases where the laser has been modified or is built in-house, the classification will be determined by the Laser Safety Officer or a person that is qualified to perform such an evaluation.

The environment in which the laser is used is also a factor in determining the overall hazard of the laser. The major considerations include:

- Indoor versus outdoor use
- Type of application

It is easier to control access to the area of the laser and establish safeguards when the laser is located indoors. Also, the specific application of the laser will be a factor in determining the overall hazard. For example, in some applications it may be possible to fully enclose the laser beam, which greatly reduces the risk of exposure. Conversely, applications which require open beam conditions during normal operations or during beam alignment procedures increase the risk of ocular and skin exposures.

The potential for accidents also depends on the level training and maturity of persons operating or working in the vicinity of a laser. A laser which falls into the hands of untrained or irresponsible individuals is a serious risk. Therefore, in evaluating the overall risk of the facility, the supervision and security over laser operations must be considered.

5.2 Hazard evaluation

5.2.1 Eye hazard

Hazard evaluation begins with a determination of the nominal ocular hazard zone (NOHZ) for all possible beam paths of the laser. The NOHZ is the space around the laser where the level of direct, reflected or scattered radiation exceeds the applicable ocular MPE . A determination of the NOHZ must take into account the following factors:

- Beam characteristics (e.g. output, wavelength, diameter, divergence)
- Optical components in the beam path (e.g. mirrors, lenses, prisms)
- Target characteristics (e.g. absorption, transmission, reflection)

While a complete description of how the NOHZ is determined is beyond the scope of this manual, an example will help illustrate the complexity involved.

Example: Assuming no atmospheric attenuation, calculate the nominal ocular hazard zone of a 20 ns, ruby laser rangefinder which emits single pulses with the following characteristics:

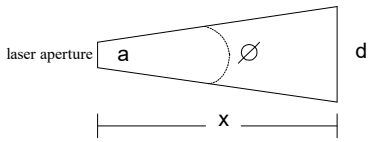
Output energy (Q)	0.1 J
Beam divergence (∅)	1×10^{-3} radians
Beam diameter (a)	0.7 cm

Solution: For a ruby laser, emitting 694 nm light with pulse duration of 20 ns, the MPE is 2×10^{-7}

Jcm^{-2} (from table 5b of ANSI Z136.1 - 2014). The nominal ocular hazard zone is the distance (x) from the laser output aperture at which the radiant exposure (Jcm^{-2}) or irradiance (Wcm^{-2}) is equal to the corresponding maximum permissible exposure expressed in the same units. In this example the radiant exposure (H) can be determined from the following equation:

$$H = \frac{4Q}{\pi d^2} = \frac{1.27\,Q}{d^2} \quad Jcm^{-2}$$

where d is the diameter of the beam at distance x as shown in figure 8.
Figure 8



Since $d^2 = a^2 + x^2\varnothing^2$

then $H = \frac{1.27Q}{a^2 + x^2\varnothing^2} \quad Jcm^{-2}$

and $x = \frac{[(1.27Q / H) - a^2]^{1/2}}{\varnothing}$ cm

The nominal ocular hazard zone is the distance (x) at which H = MPE therefore;

$$x = \frac{[(1.27Q / MPE) - a^2]^{1/2}}{\varnothing} \quad cm$$

Solving this equation using the values given yields:

$$x = \frac{[(0.127 / 2 \times 10^{-7}) - 0.49]^{1/2}}{1 \times 10^{-3}} \quad cm$$

$$x = 796{,}869 \text{ cm} \approx 8.0 \text{ km}$$

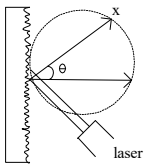
Thus, for exposure to the direct beam the laser is hazardous out to a distance of 8 km in this example. A calculation of the NOHZ for reflections of the direct beam would be even more involved and would take into account the reflective properties of target, the distance of the target and the angle of reflection relative to an observer.

In addition to exposure from specular reflections, Class 4 lasers can also produce hazardous diffuse reflections and this must be taken into account even if the target material does not produce specular reflections. The NOHZ for diffuse reflections is generally much shorter than for the direct beam or its specular reflections and can be calculated using the following equation:

$$x = [\rho Q \cos\theta / \pi\, MPE]^{1/2} \quad cm$$

where θ = angle of the observer relative to the normal of the reflecting surface and x is the distance to the boundary of the nominal ocular hazard zone as shown in figure 9.

Figure 9



Example: Calculate the nominal ocular hazard zone for a diffuse reflection of the ruby laser given in the previous example assuming that the angle of the observer (θ) is 45 deg and the spectral reflectance (ρ) is 0.2.

Solution: Substituting these values into the equation above gives:

$$x = [(0.2)(0.1)(0.707) / \pi (2 \times 10^{-7})]^{1/2}$$

$$x = 150 \text{ cm}$$

As θ increases the NOHZ for diffuse reflection decreases. When the observer is parallel to the plane of reflection θ = 90 deg and x = 0 cm.

5.2.2 Skin hazard

The evaluation must also include the potential for hazardous skin exposure. The nominal hazard zone for exposure to skin can be calculated using the same equations given above but using the MPE for skin. For wavelengths in the visible and near infrared, the MPE for skin is larger than the ocular MPE. Therefore, the nominal hazard zone for the skin is smaller than the nominal ocular hazard zone at these wavelengths.

Class 3b lasers may be hazardous only when the skin is exposed to the direct beam or specular reflections but not from diffuse reflections. Class 4 lasers present a skin hazard for exposure to the direct beam and specular reflections and may also produce diffuse reflections that are hazardous to the skin within a few centimeters of the target. Therefore, care must be taken to protect the hands when manipulating targets exposed to Class 4 laser beams even if exposure to the direct beam is avoided.

5.2.3 Visual interference

Another important aspect of hazard evaluation is determining if the laser beam will visually interfere with critical tasks. This is particular important in outdoor applications where the laser beam may project into airspace but it is also important indoors when persons have to perform operations in close proximity to the laser beam. For example, if operations have to be conducted within the NOHZ then laser goggles are generally required. However, it is important that the laser goggles allow the person to see warning lights and other physical hazards while still protecting the person from the hazardous laser light.

Most laser goggles provide protection for specific wavelengths of light and will allow other wavelengths to pass through allowing the wearer to see objects. The main problem occurs when instrument warning lights are the same color as the laser light and are not seen through the laser goggles. This situation may require replacing the warning lights with ones that produce a color other than the laser light and which are transmitted through the laser goggles.

5.2.4 Human factors

The hazard evaluation must take into account the number and types of personnel who will enter the nominal hazard zone during laser operations. In addition to the laser operators; maintenance personnel, supervisory staff, emergency response teams and even visitors may require entry into the nominal hazard zone. After determining who might enter the nominal hazard zone the following factors should

be considered:

- Level of maturity and judgment of individuals
- Level of training, experience and safety awareness
- Reliability of individuals to follow safety procedures
- Location of individuals relative to direct or reflected beams and exposure potential
- Other hazards (e.g. noise, moving objects) which may elicit unexpected actions

An analysis of these factors will determine the control measures which must be implemented including the types of entryway controls, extent of area supervision, etc.

5.2.5 Non-beam hazards

The final step in the hazard evaluation is determining what non-beam hazards are associated with use of the laser. This includes electrical hazards from the laser power supply, collateral radiation produce by the target, laser generated air contaminates and fire from combustion of objects exposed to laser light. This subject is discussed in more detail in section A.7 of this manual.

6. Laser Control Measures

Control measures are designed to reduce the level of exposure to laser radiation below the MPE for the eyes and skin. They are also designed to reduce the risk from non-beam hazards associated with laser operation including electrical, and fire hazards. The Laser Safety Officer has authority under the Radiation Protection Regulation to monitor and enforce the control measures required in the laser facility.

There are three types of control measures associated with laser operations:

- Engineering control measures
- Personal protective equipment
- Administrative control measures

The type and number of control measures required depends on the classification of the laser which in turn depends on the level of accessible radiation emitted by the laser. It may be possible to substitute alternate controls for the ones that are generally required provided that this is approved by the Laser Safety Officer after careful analysis of the situation.

6.1 Engineering control measures

Engineering control measures are those features which have been incorporated into the laser or laser system by the manufacturer or which are incorporated into the installation of the laser or facility and which serve to protect persons from the hazards associated with the use of the laser.

For each class of laser, there are some engineering control measures which are required and others which are recommended but not required. The types of engineering controls commonly incorporated into the laser or laser system are:

6.1.1 Protective housing

A protective housing is the cover or enclosure around the resonator cavity of the laser and it includes the exit port or aperture for the laser light. The protective housing prevents direct access to the internal optical components of the laser and protects persons from the laser light inside the housing. The protective housing may include panels which permit access to the internal laser radiation by service personnel.

6.1.2 Protective housing interlock

A protective housing interlock is an internal switch which is activated when the protective housing or service access panel on the protective housing is opened or removed, and which automatically causes laser operations to terminate. The interlock is designed to protect persons from exposure to laser light should the laser not be turned off before the housing or panel is removed.

The interlock can be defeated so that internal alignment of the laser beam can be performed, but this action usually requires a special tool or knowledge of the laser system to avoid casually overriding this protective feature. There must be a label near the interlock to warn persons of the presence of hazardous radiation if the interlock is defeated. Also, the laser must be designed so that the service access panel cannot be replaced while the interlock is defeated.

6.1.3 Key control

This is a master switch which turns the laser on/off and prevents unauthorized use of the laser in the event that area controls or security measures fail. The switch is generally operated by a key, although some laser systems are designed so that the master switch is operated by entering a code on a control pad or computer.

6.1.4 Safe viewing windows/portals

Systems which are designed for viewing a portion of the laser beam path may be equipped with windows or portals which permit safe viewing. Viewing is made safe by the incorporation of filters or screens in the window or portal that attenuate the laser radiation before it reaches the eye. In other designs where a target must be viewed intermittently, an interlock prevents viewing the target while it is exposed to laser light. This feature is common on microscopes used in conjunction with surgical lasers.

6.1.5 Beam path enclosure

This is a mechanical enclosure over the laser beam that becomes an extension of the protective housing. The enclosure should be made of material that will; attenuate scattered or reflected radiation to levels below the MPE, be non-combustible and prevent casual access to the direct beam. Beam paths can be partially or totally enclosed depending on the laser application.

6.1.6 Remote interlock connector

This is a connector on the back of the laser power supply that facilitates electrical connection between the power supply and an external device such as a pressure switch, light or audible alarm. The purpose of the remote interlock connector is to automatically activate a warning light or audible signal whenever the laser is energized, or to automatically turn the laser off if an entryway sensor is activated.

6.1.7 Beam stop or attenuator

This is a mechanical shutter or other device which interrupts or attenuates the beam at the exit port of the laser or anywhere along the beam path. It is used during periods when the laser beam must be temporarily stopped or when a lower beam irradiance or radiant exposure is desired. It is also used to terminate the beam at the end of its useful path.

6.1.8 Activation warning system

This can be; a light, an audible alarm, a distinct sound from laser auxiliary equipment or even a verbal countdown. It is used to alert persons just prior to activation or startup of the laser and to remind them to stand clear of the direct beam and wear laser goggles. The verbal countdown may be used for single pulse or intermittent laser operation but it is not a substitute for a warning light, an audible alarm or distinct sound that must be heard when operating continuous-wave or repetitively pulsed lasers.

6.1.9 Remote firing and monitoring

This feature allows firing and monitoring of the laser from a location that does not expose the operator to direct, reflected or scatter radiation above the MPE limit for the eyes and skin. It can be incorporated through the use of a booth or barrier that is interposed between the laser control panel and all possible beam paths.

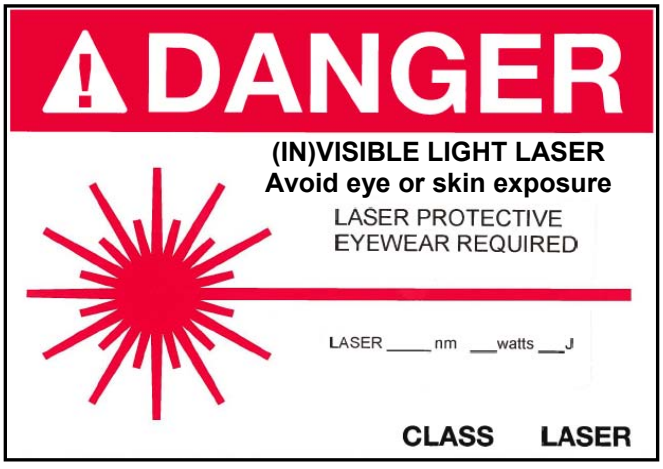
6.1.10 Warning signs/labels

There are a variety of warning signs and labels for lasers and laser systems. The type of sign or label required depends on; the specific warning that is required, the type of laser controlled area, and the classification of the laser. *ANSI Z136.1 – 2014* provides figures and specifications for the design of laser warning signs and labels including the words, symbols, colors and size to be used. In addition, the *ANSI Z136.1-2014* grandfathers laser warning signs described in previous version of this standard issued in 2007.

Laser warning signs and labels are intended to:

- Warn of the presence of a laser hazard in the area
- Indicate the specific policy in effect relative to laser controls
- Indicate the severity of the hazard present (e.g. class of laser, NHZ identification)
- Provide instructions for the use of laser goggles and for hazard avoidance

Class 3b and 4 laser warning signs noted in previous version of ANSI standard must include the following information:



- The word *"Danger"*
- The ANSI Z535 laser symbol (sunburst pattern) or the IEC 60825-1 laser symbol (sunburst

pattern within an equilateral triangle)

- Special instructions (e.g. "Laser goggles required", "Knock before entering", etc.)
- Laser type and specifications (e.g. Nd:YAG,)
- Class of the laser or laser system

Laser warning labels must provide the following special instructions:

For Class 2:

Laser Radiation - Do not Stare into Beam

For Class 2M and 3R:

Laser Radiation - Do not Stare into Beam or View Directly with Optical Instruments

For Class 3B:

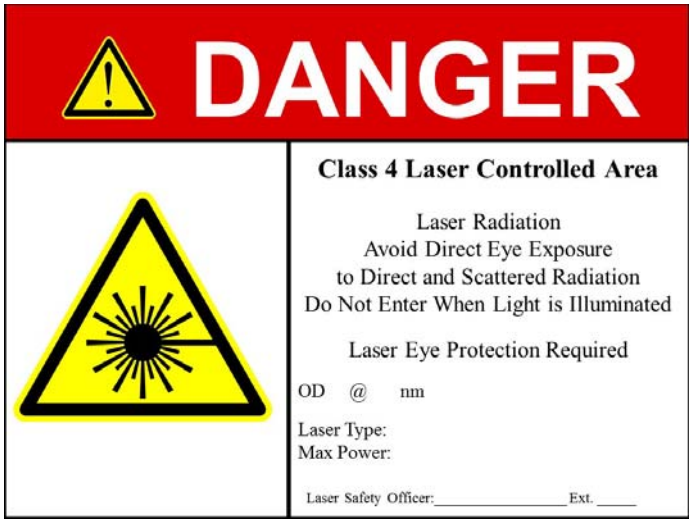
Laser Radiation - Avoid Direct Exposure to Beam

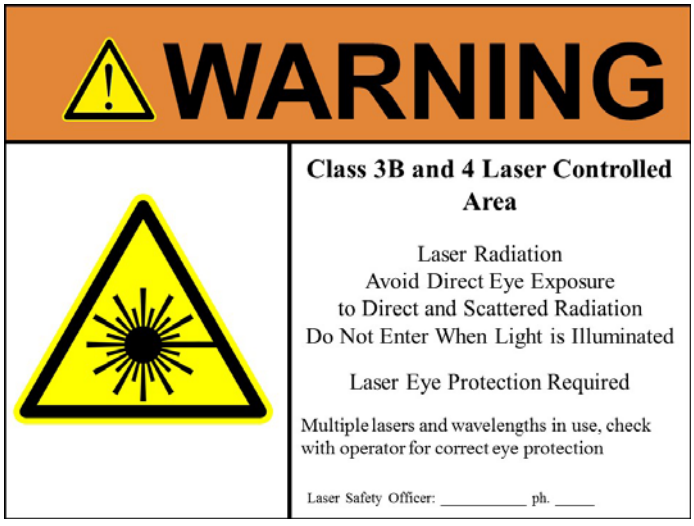
For Class 4:

Laser Radiation - Avoid Eye or Skin Exposure to Direct Beam or Scattered Radiation

Moreover, this signage applies to all medical lasers.

Class 3b and 4 laser warning signs noted in *ANSI Z136.1 – 2014* must include the following information:





It should be highlighted that the addition information required on these signs is:

- Minimum optical density of laser protective eyewear for given wavelength
- Laser safety officer contact information

6.1.11 Diffuse reflective material

Equipment and components in the laser controlled area should have surfaces that produce only diffuse reflections in order to reduce the hazard to personnel should the laser beam stray from its intended path. The equipment and components may be made of material which produces diffuse reflections or its surface can be treated or coated to produce diffuse reflections.

6.1.12 Emergency stop button

This is a large, red, mushroom shaped button that is connected to the laser power supply. Its purpose is to facilitate the immediate shutdown of a laser in the event of an emergency such as a fire or a sudden and unexpected change in beam direction that creates a hazard to personnel. It must be clearly marked with the words "Emergency Stop". In some cases, the Emergency Stop function can be assigned to other appropriately marked device that will deactivate laser or reduce output levels at or below the applicable MPE.

6.1.13 Entryway controls

Entryway controls are measures taken to control access into the laser controlled area during laser operations. Entryway controls prevent persons from being exposed to hazardous levels of laser light that might exist inside the laser controlled area and also provide security over the laser. There are two types of entryway controls:

- Doors and barriers that are interlocked to the laser power supply
- Doors and barriers that are not interlocked to the laser power supply

Interlocked doors and barriers provide the best level of protection and assurance that persons will not be injured upon entry into a laser controlled area. Provisions can be made for defeating the interlocks to allow selective entry of personnel or for those occasions when restrictions on access can be relaxed. When the use of interlocked doors and barriers is impractical, such as in a surgical suite, the use of warning lights at the entryway and hazard awareness training may substitute for the stricter measures.

6.1.14 Beam path control

Beam path control is any measure taken to reduce the nominal hazard zone around the laser. This can include the following:

- Use of a mechanically stable, optical table
- Careful placement of optical components to ensure the beam path is well defined
- Keeping the beam path above or below eye level
- Use of screens, curtains, window covers, etc

A mechanically stable, optical table and careful placement of the optical components will ensure that the beam path stays within the nominal hazard zone determined in the initial hazard analysis. The optical platform should be designed to withstand vibration, bumping or other forces which might disturb it during laser operations. Environmental forces should also be considered such as earthquakes and storms.

Careful placement of the optical components is necessary to prevent beams from straying from their intended path. This is particularly important during the initial alignment of the beam when there is a greater potential for beams to exit windows and doors or strike persons in the area. The beam should be aligned in a manner which keeps it above or below eye level once laser operations commence.

The use of screens, curtains and window covers provide protection from direct and scattered radiation should the beam suddenly stray from its normal path due to unforeseen events. Screens, curtains and window covers must be designed to attenuate the beam to levels below the MPE for the skin and eyes for a specified period of time, typically 100 seconds. Also, the barrier must not support combustion or release toxic material if exposed to laser radiation and if the barrier or curtain does not extend completely to the floor or ceiling, the possibility that the nominal hazard zone extends beyond the

barrier must be considered. Commercially available laser barriers exhibit threshold limits ranging from 5 - 500 Wcm^{-2} for different wavelengths.

6.1.15 Exhaust ventilation

Local exhaust ventilation can be used to remove air contaminates that are generated by the interaction of laser radiation with certain types of target material. The types of exhaust ventilation in use include canopy hoods and enclosing hoods. Both types remove the air contaminates without recirculation to the building, however enclosing hoods are superior to canopy hoods since they are more efficient at removing air contaminates and they provide protection from reflection of the laser light.

6.2 Personal protective equipment

Personal protective equipment is the second type of exposure control measure used in laser operations. The types of personal protective equipment used include:

- Protective eyewear
- Skin protection

Although enclosure of the laser beam is the preferred method of protecting persons from exposure to laser radiation it is often necessary to perform work around open laser beams. In this case, eye and skin protection must be utilized to protect persons who might be exposed to stray beams of laser light.

6.2.1 Protective eyewear

Protective eyewear includes; goggles, face shields, spectacles and prescription eyewear that have filters and/or a reflective coating to attenuate the laser radiation below the ocular MPE level. Protective eyewear must also be capable of withstanding the destructive power of the direct beam and its specular reflections for at least 10 seconds. Therefore, in selecting protective eyewear two characteristics must be considered:

- Optical density
- Damage threshold

The optical density (D_λ) is a measure of the attenuation of the radiation that occurs when light passes through a filter. The equation which shows this relationship is:

$$D_\lambda = \log (\Phi_0 / \Phi)$$

where: Φ_0 = incident power; Φ = transmitted power

This equation can be used to determine the required optical density of protective eyewear if the incident irradiance and ocular MPE are known. The following example illustrates how this is done.

Example: Determine the required optical density of eyewear for working with a 0.5 W laser that emits 532 nm light.

Solution: The limiting aperture for visible light is 0.7 cm corresponding to an area of 0.385 cm^2. Therefore, the irradiance (E) on the eye as defined by the limiting aperture is:

$$E = 0.5 \text{ W} / 0.385 \text{ cm}^2$$

$$E = 1.30 \text{ Wcm}^{-2}$$

The transmitted irradiance must be no greater than the MPE for this wavelength, i.e. 2.5×10^{-3} Wcm^{-2}. Therefore, the required optical density of the protective eyewear is:

$D_\lambda = \log (1.30 / 2.5 \times 10^{-3})$

$D_\lambda = 2.7$

The optical density of protective eyewear depends on the wavelength of the incident light. While most protective eyewear offers protection over a range of wavelengths, not all of the wavelengths will be attenuated to the same extent. Therefore, in selecting protective eyewear it is important to ensure that the optical density of the eyewear is adequate for the wavelength of interest.

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 and it is strongly recommended that the manufacturer be consulted when choosing eyewear for these types of lasers.

The other factor that is important in selecting protective eyewear is the damage threshold specified by the 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 result. The damage threshold varies with the type of material used in the filter and some typical ranges are given below:

Type of Material	*Damage Threshold (Wcm^{-2})*
Plastic	1 - 100
Glass	100 - 500
Coated Glass	500 - 1,000

Intense, Q-switched, laser pulses can cause filters to crack and shatter up to 30 minutes following the exposure and some filters have exhibited photobleaching after exposure to Q-switched laser pulses. Other factors that should be considered when selecting protective eyewear include:

- The need for side-shield protection and peripheral vision
- Prescription eyewear
- Comfort and fit
- Strength and resistance to mechanical trauma and shock
- Potential for producing specular reflections off of the eyewear
- Need for anti-fogging design or coatings
- The requirement for adequate visible light transmission

Protective eyewear must be clearly labelled with the optical density and wavelength for which protection is provided. In a multi-laser environment color coding of the protective eyewear is recommended.

Protective eyewear must be regularly cleaned and inspected for pitting, crazing, cracking, discoloration, mechanical integrity, the presence of light leaks or coating damage. When damage is suspected the protective eyewear should be either retested for acceptability or discarded.

When purchasing protective eyewear the wavelength, optical density, damage threshold, shelf life, storage conditions and limitations for use should be requested from the manufacturer before the purchase is made. This will ensure that the eyewear is adequate for the anticipated conditions of use.

Protective eyewear should be stored in an organized fashion to prevent damage to lenses and frames or straps. In addition, the laser safety eyewear storage location must be either outside of the lab or right at the laser lab entrance to ensure easy access before entering NHOZ area.

6.2.2 Skin protection

It is especially important to protect the skin from 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. For other wavelengths, these items may not provide adequate protection and the use of special curtains and screens may be needed to protect the skin.

6.3 Administrative control measures

Administrative control measures are the policies and procedures for the safe operation of a laser and are used to ensure compliance with the regulations. They not only supplement the engineering control measures, but help to ensure that the engineering control measures are implemented. In some cases, an administrative control measure is used in place of an engineering control measure if the later is impractical or difficult to implement. However, replacement of an engineering control measure with an administrative control measure requires careful analysis of the situation and approval from the Laser Safety Officer to ensure compliance with ANSI 136.1 -2014. The following types of administrative control measures should be implemented.

6.3.1 Security and access

Security over the laser controlled area must be maintained to ensure that only authorized personnel enter the area. It provides assurance that persons entering the laser controlled area are trained and aware of the hazards, and are properly protected from the laser radiation. A variety of access control measures can be implemented such as:

- Control over keys to entryway doors
- Control over keys and passwords for energizing the laser
- Area monitoring by security personnel, cameras, etc.

The level of security should be commensurate with the risk of unauthorized entry and exposure to the laser radiation.

6.3.2 Training

Laser safety training is provided to ensure that persons are aware of the hazards associated with the use of the laser or the hazards involved in working in the laser controlled area. The extent of training depends on the type of laser in use and its applications. In general, the greater the potential for injury, the more training required. Training may include the following topics:

- Fundamentals of laser operation
- Bioeffects of laser radiation
- Types of hazards and control measures
- Site specific procedures
- Duties and responsibilities of personnel

Persons who require laser safety training and hazard awareness include operators, maintenance and service personnel, managers and area supervisors, security and custodial staff, and visitors. Training must be provided by persons with knowledge and experience in the use of lasers and who are familiar with the regulatory requirements specified in ANSI Z136.1 - 2014.

6.3.3 Standard operating procedures

Standard operating procedures are the step-by-step instructions for operating the laser in a safe and controlled manner. The instructions include general precautions and specific directions for the type of laser in use. The following general precautions should be included in the standard operating procedure:

- Maintain adequate supervision over the laser at all times during operation.
- Keep the protective cover on the laser head at all times.
- Identify all beam paths using warning signs, non-reflective barrier tape, etc.
- Close the beam exit shutter when the laser is not in use.
- Avoid directing the laser or its reflections toward windows or area openings.
- Avoid looking at the output beam or its reflections.
- Avoid wearing jewelry or other reflecting objects while using the laser.
- Use protective eyewear at all times.
- Operate the laser at the lowest beam intensity possible for the required application.
- Expand the beam wherever possible to reduce beam intensity.
- Use the "long pulse" mode whenever possible especially during beam alignment.
- Avoid blocking the output beam or its reflections with any part of the body.
- If applicable, use an IR detector to verify that the laser is off before working in front of it or to find stray reflections.
- Avoid exposure to skin or clothing which can be burned or ignited by the laser beam.
- Establish a laser controlled area and limit access to persons trained in laser safety.
- Maintain a high ambient light level in the laser controlled area.

- Post readily visible warning signs in the laser controlled area.
- Operate the laser so that the beam is above or below eye level if possible.
- Provide enclosures for beams whenever possible.
- Set up shields to prevent unnecessary reflections.
- Use a beam dump to capture the beam and its reflections to prevent accidental exposure.
- Do not use the laser in the presence of flammables, explosives, or volatile substances.
- Follow the instructions provided in the operating manual.

In addition to the general precautions given above, the standard operating procedures should have written instructions for start-up, use and shutdown of the laser or laser system. This would include the following:

- Obtain the interlock key to the power supply of the laser from its secure location.
- Ensure that all unauthorized personnel leave the laser controlled area.
- Secure the entryway doors and activate the access control measures (e.g. entryway interlocks).
- Have emergency telephone numbers readily available.
- Ensure all persons have removed wristwatches or other reflective jewelry.
- Set up the optical components necessary to conduct the work.
- Check that all beam stops are in place and that there are no unnecessary reflective surfaces in the beam path. One block should be placed behind the first optical component. A second block should be placed behind the second optical component etc..
- Turn on the cooling water to the laser (if applicable).
- Set the laser power control to the lowest power possible.
- Ensure that appropriate laser safety eyewear is worn by everyone in the area.
- Insert the interlock key into the laser switch and unlock the laser.
- Announce loudly, with a short countdown that the laser is being turned on.
- Turn the laser on.
- Align the optical components starting with the component nearest the laser. When it is aligned, move the first beam block behind the third optical component. Repeat this procedure until the entire optical system is aligned. It is important that the laser beam be limited to one new component at a time until the system is aligned. This will minimize uncontrolled reflection during the alignment procedure.
- **Do not remove protective eyewear during the alignment phase**. The eyewear should have an optical density which allows a faint image of the beam to be seen. Use non-reflecting fluorescent paper to assist in locating the beam.
- Increase the beam power if necessary and complete the assigned task. Always use the lowest beam power necessary for the application.

- Turn the laser off.
- Remove protective eyewear and place it in the proper storage location.
- Allow the laser to cool down and then turn off the cooling water.
- Remove the key from the laser interlock system.
- Deactivate area control measures.
- Return the interlock key to its secure location.

6.3.4 Maintenance and service procedures

Maintenance is considered to be tasks specified in the operating or maintenance manual which is routinely performed. Servicing is the replacing of parts and components in the laser system and is infrequently performed. During maintenance or servicing, most of the beam precautions provided in the standard operating procedures are followed except that beam enclosures are frequently removed to perform the work. A temporary controlled area with appropriate warning signs must be established around the area of the laser if an open beam condition exists.

Only trained and qualified persons are permitted to perform maintenance or servicing of the laser system. Maintenance and servicing of the laser must be performed in accordance with the manufacturer's instruction and any departure from these instructions must be approved by the Laser Safety Officer. In addition to the type of laser safety training provided to operators, maintenance and service personnel must be trained in electrical safety and cardiopulmonary resuscitation. The buddy - system should be employed when performing maintenance on live electrical components and lock-out / tag-out procedures must be followed as described in Section II, item 12.0 of the Utilitites Department Electrical Safety System Manual.

6.3.5 Emergency procedures

Procedures must be established to protect persons and property in the event of an emergency. Emergencies include the sudden occurrence of a fire, explosion, release of toxic gas, or serious injury to personnel. The actions taken must be immediate so as to reduce the effects of the accident and should include the following measures:

- Shut the laser off using the Emergency Stop button or remove the interlock key. Instruct persons to evacuate the area.
- If there is a fire, get everyone out of the area immediately while at the same time shouting "FIRE" loudly and frequently. Activate the fire alarm pull-station. Do not try and fight the fire from inside the area but from the entrance to provide an escape route.
- Contact the Communications Control Centre at 492-5555 and describe the emergency.

6.3.6 Medical surveillance

Medical surveillance of personnel working in a laser environment is based on the need to establish a baseline against which ocular damage can be measured in the event of an acute ocular exposure. This type of medical examinations include a pre-assignment eye examination and an eye examination following an acute exposure causing injury. However, base-line eye examinations are not required at the University of Alberta.

However, any employee with an actual or suspected laser induced injury must be evaluated by a medical professional as soon as possible. If the retina injury is expected (i.e. laser light wavelengths 400-1400nm are involved), the medical evaluation shall be performed by an ophthalmologist.

Skin examinations are generally not required; however, they are recommended for individuals with a history of photosensitivity and for persons working with UV lasers. Items noted in the examination should include; personal and family skin history, current skin complaints and photosensitizing medications in use.

7. Non-Beam Hazards and Controls

Hazards which are related to the use of a laser other than exposure to the laser radiation itself are called non-beam hazards. These include electrical, chemical and physical hazards associated with the laser, laser system or target material. Safety control measures must be implemented for these hazards, many of which can be life threatening. The following paragraphs describe the types of non-beam hazards associated with lasers and the control measures that should be implemented.

7.1 Electrical hazards

Exposure to electrical components of the laser system involving greater than 50 volts is an electrical shock hazard. Risks of electric shock can occur during installation, maintenance, modification or repair to the laser and may involve the power supply or the internal components of the laser itself. The consequences vary depending on the magnitude of the exposure but in a worse-case situation can result in death by electrocution. The control measures that should be implemented include:

- Properly ground all laser equipment.
- Cover and insulate electrical terminals.
- Prevent contact with energized conductors through use of a barrier system.
- Ensure electrical warning signs and labels are posted and visible.
- Ensure "power-up" warning lights are clearly visible.
- Provide personnel with primary and refresher training in CPR.
- Use the "buddy system" or an equivalent safety measure during service or maintenance.
- Ensure that capacitors are properly discharged and grounded before service or maintenance.
- Implement and adhere to lock-out / tag-out procedures.
- Avoid excessive wires or cables on the floor.

7.2 Laser-generated air contaminates (LGAC)

Air contaminates may be generated by the interaction of the laser radiation with the target material or other components in the optical path of the laser beam. The types of contaminates that are generated vary from toxic (methyl methacrylate) and carcinogenic (benzene) chemical compounds to hazardous biological agents (microorganisms). LGACs are usually generated when the beam irradiance exceeds 10^7 Wcm^{-2} due to the vaporizing effect of the laser radiation on the absorbing material at its surface. If LGAC production is suspected, control measures must be employed to ensure that the concentration of the LGAC is less than the occupational exposure limit specified in the Chemical Hazards Regulation. The control measures commonly employed include process isolation and exhaust ventilation.

7.3 Collateral radiation

Collateral radiation includes any radiation produced by the laser or laser system other than the laser beam itself. Collateral radiation includes; x-ray, ultraviolet, visible, infrared, microwave or radiofrequency radiation which is generated by the laser power supply, discharge lamp or plasma tube. It can also be emitted from plasma produced by metal targets after the absorption of pulsed laser radiation in excess of 10^{12} Wcm^{-2}.

7.3.1 X-radiation

X-rays can be produced by high voltage vacuum tubes and laser-metal induced plasma. Lead shielding may be required to keep exposure below the maximum permissible exposure level specified in the Radiation Protection Regulation.

7.3.2 Ultraviolet and visible radiation

UV and visible radiation can be produced by discharge lamps used to pump the laser. Protection is normally afforded by the protective housing over the laser, however additional UV shielding may be required when the housing is removed for maintenance or servicing of the laser while the beam is on.

7.3.3 Radiofrequency radiation

Radiofrequency radiation is used to excite plasma tubes and Q-switches in some lasers. In order to ensure that the occupational exposure limits for RF radiation is not exceeded, the control measures specified in Health Canada Safety Code 6 should be followed.

7.3.4 Plasma radiation

Plasma radiation is diffuse UV, blue light or x-rays emitted by the target material from interaction with the laser radiation. It can be an exposure hazard at high irradiance levels and may require protective eyewear with an optical density of 2-3 for UV. It is most commonly produced from cutting and welding of metals by CO_2 and Nd:YAG lasers.

7.4 Fire hazards

Irradiance levels in excess of 10 Wcm^{-2} can ignite combustible material. Most Class 4 lasers have irradiance levels exceeding 10 Wcm^{-2} and are therefore fire hazards. Flammable substances can be ignited at even lower irradiance levels making Class 3b lasers possible fire hazards in the presence of flammable substances.

Barriers and enclosures around a laser must be capable of withstanding the intensity of the beam for a specific period of time without producing smoke or fire. It is important to obtain information from the manufacturer on the properties of the barrier or enclosure to ensure it will provide adequate protection under worse-case conditions of exposure. Other items such as unprotected wire insulation and plastic tubing can catch on fire if exposed to sufficiently high reflected or scattered beam irradiance. When working with invisible wavelength lasers this should be kept in mind since it may not be obvious that these surfaces are exposed.

The control measures include using non-combustible material in the laser controlled area especially in the beam path and having adequate fire protection of the facility including sprinkler systems, fire extinguishers, etc. The National Fire Protection Association Code #115 provides further information on controlling laser induced fires.

7.5 Explosion hazards

High pressure arc lamps, filament lamps, capacitor banks, target material or items in the path of the laser have the potential for disintegrating, shattering or exploding. Gases used as part of the laser itself or as part of the target material can become heated and explode. In addition, the beam may cause an explosion when accidently directed onto a gas cylinder, regulator or delivery hose. Where an explosion hazard exists, adequate enclosures must be installed to protect persons and equipment from the potential effects of the explosion.

7.6 Compressed gases

There are a variety of gases used in laser systems with varying toxic and hazardous properties. All compressed gases are physical hazards by virtue of the high pressure under which the gas is contained. If the gas is released in a rapid and uncontrolled fashion due to a rupture of the cylinder head, the cylinder can become a dangerous projectile causing damage and injury. If the gas is toxic (carbon monoxide) or corrosive (hydrogen chloride) it can burn tissue and cause pulmonary edema if allowed to leak into the work space. Even an inert gas such as argon or helium can cause asphyxiation if it leaks into an enclosed space and displaces oxygen. The safety control measures used with compressed gases include:

- Isolation of the gas cylinder from personnel
- Proper storage of the gas cylinder when not in use (capped, supported, ventilated enclosure, segregated)
- A system for isolating and purging the gas line after use
- Proper cylinder identification
- Area gas detection

7.7 Dyes and solvents

Some lasers use dyes dissolved in a solvent as the laser medium. The dye is a fluorescent organic compound that may be toxic, mutagenic or carcinogenic. The solvent may be flammable and easily absorbed through the skin carrying the dye compound with it. Therefore, care must be exercised in preparing the dye solutions, transferring the dye solutions into the laser cavity and in cleaning or maintaining the laser system. The safety control measures used with laser dye solutions include:

- Material Safety Data Sheet available and referenced
- Use of less hazardous solvents (e.g. ethanol instead of methanol)
- Personal protective equipment (gloves, lab coat, respirator)
- Use of fume hoods or glove boxes to prepare dye solutions
- Containment of dye solution transfer pumps and reservoirs

8. Accident History and Analysis

Laser accidents can be divided into the following classes:

- Beam exposure accidents
- Non-beam accidents

Beam exposure accidents occur when a person is exposed to laser radiation at a level above the MPE for the eyes or skin. Other beam related accidents occur when the laser radiation causes a fire, explosion, production of toxic gas or aerosol, plasma radiation, or damage to equipment. Non-beam accidents occur as a result of exposure to electrical current, hazardous gases or liquids, collateral radiation, mechanical malfunction or other physical hazards.

8.1 Beam exposure accidents

Exposure to the direct beam or reflected laser radiation can cause serious eye or skin damage. Exposure to the eye is worse than exposure to the skin because of the critical function of the eye and its reduced potential for recovery. Eye and skin accidents have commonly occurred from:

- Failure to wear personal protective equipment (eyewear and clothing)
- Improper selection of personal protective equipment
- Equipment failure
- Misaligned optics
- Improper procedures
- Unanticipated exposure during laser operations
- Intentional exposure of personnel

Failure to wear personal protective equipment or the improper selection of personal protective equipment is due to lack of training, complacency, the desire to expedite operations or to save money. It is the responsibility of management to ensure that operators are properly trained and that refresher training is provided on a regular basis. Complacency and the desire to take short cuts to save costs or expedite operations is due to a lack of discipline in the workplace and a lack of understanding of the necessity for proper safety equipment. Management must ensure that the workplace is adequately supervised and that safety inspections are conducted on a regular and unannounced basis. Management must also provide adequate funding for personal protective equipment and other safety devices to provide for the best protection of their workers.

The breakdown or the failure of safety equipment is due to the improper selection of equipment (equipment should be selected based on the worst case conditions of use), failure to inspect or test safety equipment on a regular basis, and manufacturer defects (only purchase from reliable sources). These principles also apply to other types of safety equipment such as protective laser barriers.

Unanticipated exposures are often caused by the failure to follow proper written procedures. With respect to lasers, the eye injuries occur most often during beam alignment operations. In fact, improper beam alignment accounts for 60 percent of all laser accidents. Failure to establish and follow approved beam alignment procedures has resulted in numerous cases of partial or complete blindness in the exposed eye of the individual. The following case studies illustrate the problem:

Case 1: While performing a beam alignment of a 0.5 watt, Ti-Sapphire laser (720 nm) a postdoctoral student was exposed in the left eye while not wearing protective eyewear. He was making changes to the beam optics and thought that the laser was off and moved his eye into the beam and saw a bright flash. He then noticed a dark spot in his field of vision. An ophthalmologic examination later revealed a scotoma (burn) on the retina.

Case 2: While performing a beam alignment of a Nd:YAG laser (532 nm) at low power a worker was exposed in the right eye while not wearing protective eyewear. He was in the process of bending down to look at a power meter in the beam path when he saw a bright green flash from a reflection of the beam that had entered his eye. Because he experienced no immediate pain he was not aware of the retinal damage that had occurred. He later discovered that he had a persistent blind spot and the possibility of permanent peripheral vision loss.

Persons often remove protective eyewear during the course of a beam alignment because they cannot see the beam with the eyewear on. This problem is due to improper selection of eyewear for beam alignments. Lower optical density alignment goggles need to be purchased to allow visualization of a faint trace of the beam while performing the alignment. Some other steps which can be taken to reduce the risk of hazardous exposure during beam alignments include:

- Perform the alignment at the lowest possible power and longest pulse duration
- Use IR/UV viewing cards
- View diffuse reflections only
- Use a beam finder for IR wavelengths
- Perform the alignment of non-visible light laser using a coaxial, low power, visible laser
- Isolate the process and minimize the possibility of stray beams or reflections through the use of beam blocks

Skin exposures, although less serious than ocular exposures, also occur because of failure to follow proper procedures. Often a person will accidentally pass a hand through the beam due to inattention, fatigue or stress while performing the task. Procedures that involve working in close proximity to the laser should first be performed as a "dry run" in order to gain familiarity with the hand movements required for the task. In this way, mistakes and inadvertent exposures are less likely to occur.

Exposure to the direct beam or reflected laser radiation can also cause serious damage to equipment / furnishings and the possibility of fire, release of toxic gas or even explosions. The laser must be securely supported and aligned to prevent unexpected motion of the beam and subsequent exposure of combustible material. The two types of lasers most commonly associated with fires are CO_2 and Nd:YAG lasers. One study showed that 16 percent of all non-personnel related laser accidents were due to fires. Therefore, provisions must be made to prevent and respond to laser related fires should they occur. The use of properly designed laser barriers and curtains go a long way to preventing laser fires from occurring. Although expensive, commercial barriers provide the best level of protection for personnel outside of the nominal hazard zone and the best assurance of preventing laser fires.

8.2 Non-beam accidents

Non-beam accidents account for only 10 percent of all reported laser related accidents although the incident rate is probably much higher since most are investigated and reported as general safety or industrial hygiene related accidents. However, it is clear that these types of accidents are among the

most serious of laser related accidents and can result in permanent injury or death. Therefore, the laser user must appreciate the potential risk of non-beam accidents and take appropriate safety precautions. The types of accidents that have been reported include:

8.2.1 Electric shock

Electric shock ranges in severity from mild tingling to electrocution although only the worst cases are usually reported. One study showed that 25 percent of reported electric shock cases resulted in death by electrocution.

8.2.2 Fire

Fire can result from overheating of electric circuits in the laser system or from combustion of material exposed to the laser beam. Fire accounted for 25 percent of all non-beam accidents in a recent study of laser related accidents.

8.2.3 LGACs

Laser Generated Air Contaminates (LGACs) are often reported as exposure to toxic "fumes" given off by material from exposure to the laser beam. They can arise from a variety of target material including metals, combustibles and living tissue of patients treated with laser radiation. LGAC exposure accounted for 9 percent of all non-beam accidents in a recent study of laser related accidents.

A breakdown of the effects of non-beam related accidents was conducted in a recent study. The results of the study showed that permanent injury including death occurred in 14 percent of all reported cases and that temporary impairment occurred in 42 percent of the reported cases. This study underscores the seriousness of non-beam laser accidents and the need for adequate control measures to prevent their occurrence.

B. Administrative Procedures

1. Regulations

Class 3b and 4 lasers are regulated in Alberta under the Radiation Protection Regulation. This regulation requires that Class 3b and 4 lasers be registered before they may be used. The registration process requires a formal compliance inspection to be carried out to ensure that the laser meets certain specified safety standards before it may be registered. The safety standard that has been adopted under the Radiation Protection Regulation for non-medical Class 3b and 4 lasers is the American National Standard for Safe Use of Lasers, ANSI Z136.1 -2014. The medical Class 3b and 4 lasers must meet the requirements of CSA Standard for Safe Use of Lasers in Health Care, CAN/CSA Z386-14, adopted by the Radiation Protection Regulation.

In 1998, the Radiation Health Administration Regulation came into existence which permitted the Government of Alberta to enter into a legal agreement with various professional organizations for the purpose of delegating its authority to the professional organizations for registration of lasers owned by their members. Under this plan, the University of Alberta became an Authorized Radiation Health Administrative Organization on December 16, 2000 giving it the authority to register all Class 3b and 4 lasers in its possession.

The Radiation Health Administration Regulation also permits the Government of Alberta to enter into a legal agreement with qualified companies for the purpose of delegating its authority for inspection of Class 3b and 4 lasers throughout the province. Under this plan, the University of Alberta, Department of Environment, Health and Safety (EHS) became an Authorized Radiation Protection Agency (ARPA) giving it authority to inspect Class 3b and 4 lasers owned by the University of Alberta. Although EHS provides this service, owners of University of Alberta lasers may also engage the services of other ARPAs if they so desire, although most will prefer to take advantage of the free service offered by EHS that is available for selected laser types.

2. Inspection and Registration

To register a Class 3b or 4 laser, the owner of the equipment must apply to register the laser with the Department of Environment, Health and Safety (EHS). The application form is available from the on the EHS website.

Upon receiving the application form, the designated EHS staff member will make arrangements with the owner of the laser to perform a compliance verification of the laser and the associated facility. Items checked will include the existence of safety features designed into the laser, the use of personal protective equipment, the implementation of safety procedures and other items specified in ANSI Z136. 1 - 2014. An inspection report will then be sent to the owner of the laser. Any deficiencies that are identified must be corrected before the laser can be registered, and the owner of the laser will be required to provide evidence that corrective action has been taken.

Upon receiving written notification that corrective action has taken place, the designated EHS staff member will submit the inspection report and any follow-up correspondence to the University of Alberta signing authority for laser Registration Certificates. The Registration Certificate will then be issued to the owner of the equipment.

The Registration Certificate allows the laser to be operated and is valid for the time duration as indicated in the certificate. Prior to the expiration of the Registration Certificate, the owner of the equipment will receive a notice of the upcoming laser registration expiry. The inspection and registration process described above must then be repeated if the laser is to continue to be used. There is no requirement to register a laser that is simply kept in storage; however, the status of Class 3b and 4 lasers in storage must be reported to the Radiation Safety Officer following any changes in storage location or disposition.

3. Personnel Responsibilities

3.1 General

Every person owning, installing, supplying, operating or servicing Class 3b or 4 lasers or laser systems shall take all reasonable precautions to protect persons from laser injury. All persons involved in the daily operation of a Class 3b or 4 laser shall:

- Take all reasonable precautions to ensure the worker's own safety and the safety of fellow workers.
- Use the personal protective equipment and other safety devices provided by the employer.
- Report incidents and exposures to the Laser System Supervisor.

3.2 Laser Safety Officer (LSO)

The LSO, who is also the Radiation Safety Officer at the University of Alberta, is responsible for the evaluation and control of laser hazards and for monitoring and enforcing compliance with the requirements given in this manual. The LSO is required to:

- Ensure that the necessary records required by applicable government regulations are maintained including registration certificates, compliance verifications reports, training records, lists of laser users, etc..
- Perform inspections of the laser controlled area and accompany regulatory agency inspectors during their visits.
- Ensure corrective action is taken on noted deficiencies.
- Investigate laser related accidents and initiate appropriate action including the preparation of reports to regulatory agencies.
- Determine the adequacy of laser safety control measures including standard operating procedures, maintenance and service procedures, and modifications to the laser system or procedures.

3.3 Laser System Supervisor (LSS)

The LSS is usually the person listed on the laser Registration Certificate. The LSS must be knowledgeable of the requirements for laser safety, the potential laser hazards and associated control measures, and the policies, practices and procedures pertaining to the laser under the LSS's control. The LSS is required to:

- Provide appropriate instructions and training material on laser hazards and control measures to all personnel who may work with lasers under the LSS's jurisdiction.
- Ensure that measures are taken to protect employees, visitors and the general public from the hazards associated with use of the laser.

- Submit the names of individuals scheduled to work with the laser to the LSO and submit information as requested by the LSO for training.
- Provide immediate notification of known or suspected accidents involving the laser(s) under the supervisor's jurisdiction to the LSO.
- If necessary, assist in obtaining appropriate medical attention for any employee involved in a laser accident.
- Obtain approval from the LSO before permitting the use of new or modified lasers under the LSS's jurisdiction.
- Ensure that the standard operating procedures for the safe use of the laser are provided to users of the laser.

3.4 Laser users

Laser users are employees who are authorized by the LSS to energize or work with or near a laser. Laser users are required to:

- Comply with the safety rules and procedures prescribed by the LSO and the LSS.
- Maintain familiarity with all operating procedures for the laser.
- Provide immediate notification of known or suspected accidents involving the laser(s) under the laser user's jurisdiction to the LSS or to the LSO if the LSS is unavailable.

4. Security and Area Control

4.1 Signage

Laser area warning signs must be posted on the entrance door(s) to the laser controlled area.

4.2 Visitors

Visitors that are granted permission to enter an area where a Class 3b or 4 laser is operated must be accompanied by an approved staff member and must be provided with the following:

- Information on potential eye and skin hazards
- Information on safety precautions (e.g. no bending, sitting down or entering laser hazard zone)
- Laser protective eyewear

4.3 Staff

Admission of staff members is subject to the following restrictions:

- Only authorized staff members are permitted entry into the laser controlled area during laser operations. All other staff are considered to be a visitor to the laser controlled area.
- Persons requiring access to the laser controlled area must be provided with laser hazard awareness training and personal protective equipment before hand.

5. Training

All workers who are likely to be exposed to Class 3b or 4 lasers owned by the University of Alberta must be well informed of the potential hazards of the laser and the precautions to be taken to protect themselves and other persons from those hazards. To comply with this requirement the following must

be brought to the attention of each worker:

- The workers responsibilities and duties under the Act and Regulation
- The type of laser sources with which the worker will be working
- Laser protection principles and maximum exposure limits for lasers
- The uses and limitations of the facility, laser equipment and laser sources the worker will use
- Known or suspected health hazards associated with the lasers

For more information on laser safety training, contact EHS.info@ualberta.ca.

6. Medical Assessments

In the event of a suspected or actual laser injury to the eye(s) of a person a medical assessment will be required. If the retina injury is expected (i.e. laser light wavelengths 400-1400nm are involved), the medical evaluation shall be performed by an ophthalmologist.

7. Records

The following records shall be maintained with respect to the laser and laser system:

- Registration Certificates (current and previous)
- Compliance verification reports (current and previous)
- Internal audits and inspection reports (indefinite period)
- Maintenance and service records (indefinite period)
- Accident and investigation reports (indefinite period)
- List of laser users (current)
- Training records (indefinite)

8. Compliance and Enforcement

The University of Alberta will ensure compliance with the Act and Regulation for lasers under its jurisdiction. Compliance will be enforced by:

- Requiring the owner of the laser to implement the regulatory standard for lasers, ANSI Z136.1 - 2014,
- Requiring the owner of the laser to take remedial action to correct any condition which contravenes the Act or Regulation, or which is inconsistent with safe operating practices,
- Prohibiting the use of a laser that;

  (a) is in such a condition or at such a location that it cannot be used without risk of unnecessary exposure to personnel or,

  (b) is used in such a manner that it causes risk of unnecessary exposure to personnel or,

  (c) is exposing persons to laser radiation beyond the maximum permissible exposure limit.

Owners of Class 3b and 4 lasers shall comply with all written directives issued to them by the University of Alberta in its capacity as an Authorized Radiation Health Administrative Organization.

9. Investigations

If an overexposure or an incident that has the potential of causing overexposure of a person occurs, the Laser System Supervisor shall forthwith notify the Laser Safety Officer as to the time, place and nature of the overexposure or incident. The Laser Safety Officer, together with the Laser System Supervisor will carry out an investigation into the circumstances surrounding any complaint, incident or suspected overexposure, and prepare a report outlining the circumstances and the corrective action required to prevent a recurrence of the overexposure or incident.

10. Penalties

Failure to respond to a compliance directive issued by the University of Alberta in its capacity as an Authorized Radiation Health Administrative Organization may result in suspension or revocation of the Registration Certificate of the laser, prohibition of equipment use, seizure of equipment or referral for disciplinary action.

A person who intentionally contravenes the Alberta Radiation Protection Act/Regulation or who fails to comply with a directive made by an Authorized Radiation Health Administrative Organization under the Act/Regulation may also be subject to fines and/or prosecution under the Radiation Protection Act by the Director of Radiation Health for the Province of Alberta.

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