# LASER HAZARDS

## 1. Laser Safety Parameters

Power output, beam diameter, pulse length, wavelength, beam path, beam divergence, and exposure duration are parameters of a laser device that are useful to help determine the risk of personal injury. However, concepts such as the maximum permissible exposure (MPE), accessible exposure limit (AEL), optical density (OD) and nominal hazard zone (NHZ) are also important for the laser operator to understand and quantify the potential danger of laser radiation.

### 1.1 Maximum Permissible Exposure (MPE)

Maximum permissible exposure (MPE) is the maximum irradiance or radiant exposure of the light source (measured in $W.cm^{-2}$ or $J.cm^{-2}$), that under normal circumstances is considered safe and has negligible probability of causing any damage to the eyes or skin. The ANSI Z136.1 standard tables 5, 6, and 7 provide calculations of the eye and skin MPE values for particular wavelengths and exposure durations. Note that the exposure duration basis for the MPEs listed in the ANSI Z136.1 tables are as follows:

- 0.25 s: The human aversion time (i.e. blinking, turning away) for a bright light stimulus, which only applies to visible wavelengths (400-700 nm).
- 10 s: The time period chosen by the ANSI Z136.1 committees that represents the “worst case” time period for ocular exposure to an infrared (principally near infrared) laser beam.
- 600s: The time period chosen by the ANSI Z136.1 committees that represents the typical "worst case" time period for viewing visible diffuse reflections during tasks such as alignment.
- 30,000s: The time period that represents a full one-day (8 hour) occupational exposure.

For single pulsed lasers, the exposure duration used in determining the MPE is equal to the pulse duration, as defined at the half-power point. The total exposure duration ($T_{max}$) of a train of pulses is required to determine the MPE for repetitively pulsed lasers. For repeated exposures to wavelengths in the UV range (180 to 400 nm), the exposure dose is additive over 24 hours, regardless of the repetition rate.

The MPE is a useful parameter as it is used to determine the appropriate nominal hazard zone (NHZ) and the optical density (OD).

### 1.2 Nominal Hazard Zone (NHZ)

The nominal hazard zone (NHZ) is the distance from the laser source within which the level of direct, scattered or reflected laser light emitted during laser operation exceeds the MPE. Outside of the nominal hazard zone, the level of laser radiation is less than the applicable MPE and therefore safe for the eye or skin (see Figure 1). The NHZ is often used to define the Laser Controlled Area (LCA). In some situations, when the laser is located in an enclosed location such as a whole room, the whole room is defined as the Laser Controlled Area (LCA) even if the NHZ is smaller or greater than that area.

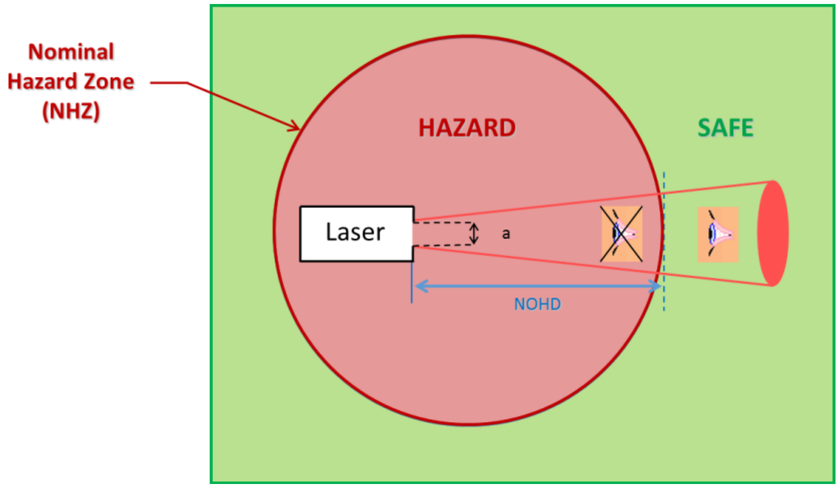



**Figure 1.** Definition of the Nominal Hazard Zone (NHZ).

## 1.3 Optical Density (OD)

The optical density is defined using the equation below:

$$OD = \log_{10}\left(\frac{H_0}{MPE}\right)$$

Where $H_O$ is the anticipated worst case incident irradiance or radiant exposure.

The OD values is the safety rating (transmission) value used to determine the level of eye protection for safety eyewear. The table below shows the transmission of laser radiation for the various OD values.

**Table 1.** Optical Density and the various transmission level.

| OD | % Transmission |
|---|---|
| 0 | 100 |
| 1 | 10 |
| 2 | 1 |
| 3 | 0.1 |
| 4 | 0.01 |
| 5 | 0.001 |
| 6 | 0.0001 |

## 1.4 Accessible Emission Limit (AEL)

The AEL is the maximum irradiance or radiant exposure a laser (from a specific class) can emit/produce. It gives an indication of the potential hazard. In practice the AEL is determined as follows:

$$AEL = MPE \times LA$$

Where LA is the area of limiting aperture (e.g. 7mm for the eye exposed to visible light)

The AEL values are mainly used for classification of lasers; they are not immediately useful to a user who wants to know if his/her particular setup is safe. However, the classification scheme can be used to help make very simple decisions. For instance, if the power level is always kept below that required for a Class 2 device then it means that accidental exposure to the beam will not be hazardous to the users.

# 2. Laser Classification

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

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

In addition to these general parameters, lasers are classified in accordance with the AEL, which is the maximum accessible level of laser radiation permitted within a particular laser class. The ANSI standard laser hazard classification is based on the potential for a laser to exceed the AEL and is described in Table 2.

**Table 2:** Laser Systems Classification scheme. ANSI Z136.1 2014.

| | |
|---|---|
| **Class 1** | These lasers are considered to be incapable of producing damaging radiation levels during operation, and exempt from any control measures. Class 1 laser systems may contain a more hazardous laser embedded in the enclosure, but no harmful levels of the laser radiation can escape the system enclosure. For Class 1 lasers containing an embedded higher class of laser, the enclosure must be interlocked. |
| **Class 1M** | These lasers are considered to be incapable of producing hazardous exposure conditions during normal operation unless the beam is viewed with collecting optics (e.g. telescope) and is exempt from any control measures other than to prevent potentially hazardous optically aided viewing. |
| **Class 2** | These lasers emit in the visible portion of the spectrum (400 nm to 700 nm) and eye protection is normally afforded by the aversion response. |
| **Class 2M** | These lasers emit in the visible portion of the spectrum (400 nm to 700 nm) and eye protection is normally afforded by the aversion response for unaided viewing.<br>However, Class 2M lasers are potentially hazardous if viewed with collecting optics (e.g. telescope). |
| **Class 3R** | These lasers have a reduced control requirements and are potentially hazardous under some direct and specular reflection viewing conditions if the eyes are appropriately focused and stable, but the probability of an actual injury is small. These laser will not pose either a fire hazard or diffuse reflection hazard. |
| **Class 3B** | These lasers are medium power lasers that have an output power between 5 mW and 500 mW. They may be hazardous under direct and specular reflection viewing conditions; however, they normally do not present a fire hazard, diffuse reflection hazard, nor a laser generated air contaminant (LGAC) production hazard. Protective eyewear is required when working with Class 3B. |
| **Class 4** | These lasers have an output power exceeding 500 mW. They are a hazard to the eyes and skin from the direct beam, they may also pose a fire hazard, diffuse reflection hazard, and may also produce LGAC and hazardous plasma radiation. Protective eyewear is required when working with Class 4. |

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

# 3. Essential Laser-Tissue Interactions

The nature and severity of laser induced injury depends on how the laser radiation interacts with the tissue exposed. Laser light incident upon biological tissue will be reflected, transmitted, and/or absorbed and the occurrence of these effects is dependent on the properties of the tissue exposed, wavelength and exposure duration. As expected, it is the absorbed laser radiation that is of interest when talking about tissue damage. Upon absorption of laser radiation atoms/molecules are excited and the absorbed energy is dissipated as either thermal energy (heat) or chemical reaction (ionization or bond breaking). The level of absorption of laser radiation by a tissue is referred to as penetration depth and is highly dependent on wavelength. Eye hazards and skin hazards sections below illustrate the skin and eye penetration depth of various wavelengths.

There are 3 types of laser-tissue interactions that lead to tissue damage (see Figure 2):

- Photothermal
- Photochemical
- Thermomechanical

Each of these processes depends on wavelength, exposure duration, the type of tissue exposed (eye or skin) and irradiance.

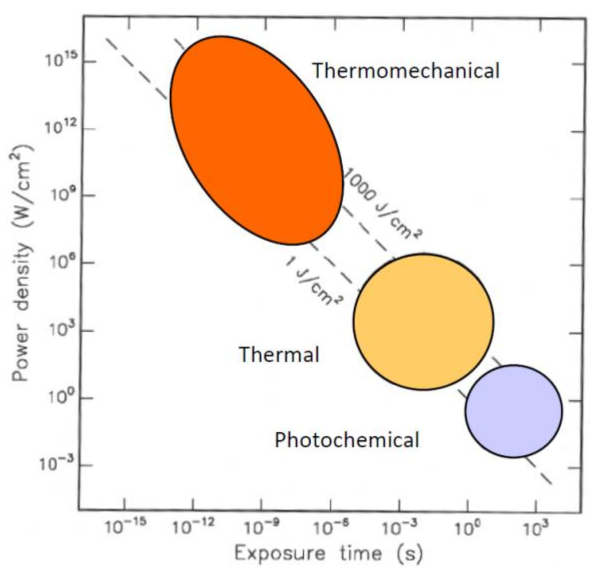



**Figure 2.** Dependence of laser-tissue interaction on exposure duration and irradiance.

**Photothermal effect** is the most common effect; it leads to an increase in the tissue temperature upon exposure to laser light. The incurred injury will be instant and will depend on the tissue temperature reached (see Table 3). However, if the increase in temperature occurred over a short period of time the tissue may be able to withstand higher temperature without being damaged and if the increase in temperature occurs over a long period of time the damage will occur at a lower threshold.

**Photochemical effect** occurs at temperatures that are not high enough to cause thermal damage. This process is dominant at shorter wavelength (e.g. UV) where the photon energy is high enough to cause ionization, create free radicals, etc. It is a cumulative effect so that short exposure at high irradiance and long exposure at small irradiance lead to the same tissue damage.

**Thermomechanical effect** occurs when the heating of the tissue is very rapid and localized causing a rapid expansion of the tissue which in turn leads to the formation of a mechanical shock wave. The shock wave then propagates and damages even more tissue and can even cause ablation. Because this process only happens at short exposure time, it can only be observed with ultrashort laser pulses (on the order of the picosecond, $10^{-12}$ s).

**Table 3.** Photothermal effect at various temperatures.

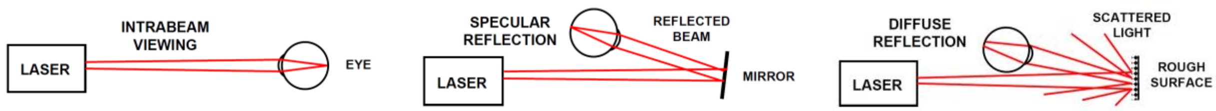
| Temperature in the tissue | Effect on the tissue |
|---|---|
| < 60°C | Tissue hyperthermia, edema |
| > 60°C | Protein denaturation, tissue necrosis |
| 100°C | Water in tissue boils, tissue dehydration |
| > 100°C | Result in carbonization and melting |

# 4. Beam Hazards – Eye and Skin

Eye and skin exposure to the laser beam is not limited to direct beam exposure (see Figure 3). Particularly for high power lasers (Class 3B and 4), exposure to beam reflections may be just as damaging as exposure to the primary beam (causing vision impairment, skin burn, set fires, etc.). The different type of eye or skin exposure are detailed below:

- ***Intrabeam exposure*** means that the eye or skin is exposed directly to all or part of the laser beam; i.e. the eye or skin is exposed to the full irradiance or radiant exposure.
- ***Specular reflections*** from mirror surfaces can be nearly as harmful as exposure to the direct beam. Specular reflection can occur from a flat, convex or concave surface. A flat surface will only change the direction of the beam (not its beam diameter), a convex surface will cause the beam to spread, while a concave surface will cause the beam to converge (reducing the beam diameter as it propagates).
- ***Diffuse reflections (or scattering)*** occurs when the beam incident on a surface will be reflected in many directions. Mirror-like surfaces that are not completely flat, such as jewelry or metal tools, may cause diffuse reflections of the beam. These reflections do not carry the full power or energy of the primary beam, but may still be harmful, particularly for high power lasers. In addition, diffuse reflections from Class 4 lasers are capable of initiating fires.

It is also important to note that whether a surface is a diffuse reflector or a specular reflector will depend upon the wavelength of the beam and the surface roughness of the material. A specular surface is one that has a surface roughness less than the wavelength of the incident light; as a result, a surface that would be a diffuse reflector for a visible laser may be a specular reflector for an infrared laser beam. Figure 7 shows the difference between the various types of eye or skin exposure.




(a) (b) (c)

**Figure 3.** Different type of exposure to laser radiation,
(a) Direct beam, (b) Specular reflection, (c) Diffuse reflection.

## 4.1 Beam Hazards - Eye

The location and extent of eye injury depends on the wavelength and laser output. Corneal opacities (cataracts) or retinal injury may be possible from exposures to excessive levels of either visible or invisible laser radiation. Eye hazards can be easily avoided by having engineered safety controls in place and/or using laser safety eyewear appropriate for the specific laser system.

The anatomy of the eye is shown in Figure 4 and the components of the eye most susceptible to laser damage are described below:

- **Cornea –** refracts the light entering the eye onto the lens. It is a living tissue directly exposed to the environmental elements and only protected by a thin tear film. The corneal epithelium has one of the highest metabolic rates in the entire body rejuvenating itself every 24 to 48 hours. The cornea contains no blood vessels and is extremely sensitive to pain.
- **Iris –** Circular pigmented membrane that lies behind the cornea and in front of the lens. The iris regulates the amount of light that enters the eye.
- **Pupil –** Circular opening in the center of the iris through which light travels to reach the lens and then the eye's photoreceptors. The iris controls the widening and narrowing (dilation and constriction) of the pupil.
- **Lens –** Transparent structure situated behind the pupil, the lens provides the fine tuning of the eye, focusing the incoming light onto the retina. The lens has a slow metabolism and it tends to harden and become yellow with age. In some cases, the lens becomes cloudy, which affects the person's vision, this condition is called cataract.
- **Sclera –** It is a dense fibrous shell that maintains the spherical shape of the eye as well as the internal pressure.
- **Retina –** It is a light-sensitive layer that lines the interior of the eye. It is composed of photoreceptors called rods and cones. Rods are the photoreceptors typically used for night and peripheral vision, while the cones are the photoreceptors used for color and resolution.
- **Macula –** small area in the center of the retina where the light is focused by the lens. This area is packed with photoreceptors providing us with the ability to read and see in great details.
- **Fovea –** Small indentation at the center of the macula; it is the area with the greatest concentration of cone cells. When the eye is directed at an object, the part of the image that is focused on the fovea is the image most accurately registered by the brain.

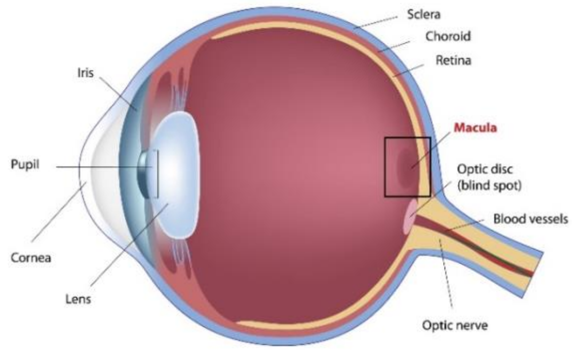



**Figure 4.** Anatomy of the human eye.

Laser irradiation of the eye may cause damage to the cornea, the lens or the retina (e.g. macula or fovea), depending on the wavelength of the light, the energy absorption characteristics of the ocular media and the laser beam direction. Lasers emitting UV, visible or infrared wavelengths can cause biological damage by depositing thermal energy (i.e. heat) in a small area or by photochemical processes. Note that the damage/injury to the eye will be greater if the person is working in dark environment whereby the pupils are fully dilated. As a result, it is very important that work with laser light is carried out in well-lit environments. Table 4 and Figure 5 summarizes the various ocular tissues at risk for different spectral regions.

**Table 4.** Summary of ocular tissues at risk for different spectral regions.

| Spectral Region | Wavelength (nm) | Ocular tissue at risk |
|---|---|---|
| Ultraviolet C | 180 – 280 | Cornea |
| Ultraviolet B | 280 – 315 | Cornea |
| Ultraviolet A | 315 – 400 | Lens |
| Visible Light | 400 – 700 | Retina |
| Near Infrared | 700 -1,400 | Retina |
| Mid Infrared | 1,400 – 3,000 | Cornea |
| Far Infrared | 3,000 – 10,000 | Cornea |

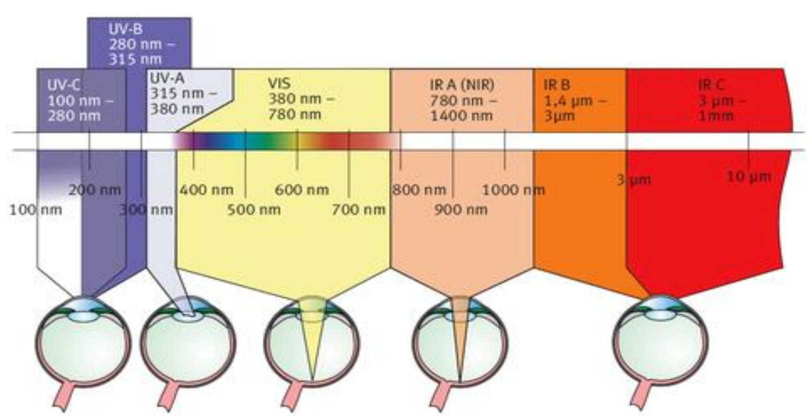
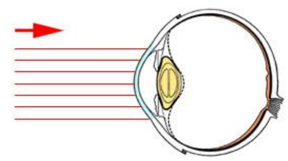
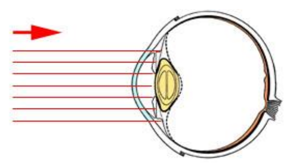
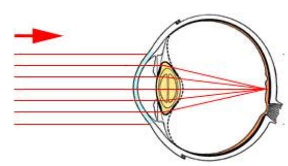
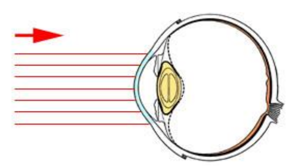



**Figure 5.** Eye penetration depth for various wavelengths

Table 5 outlines the biological damage of the different wavelengths on the eye. However, it is important to note that there are two transitions between spectral regions that can damage both the cornea and the retina. These are located at the spectral bands separating UV-A and visible light, or the near and mid infrared. An example of this hazard would be the emission from a Nd:YAG laser in the near infrared region (1064 nm). This wavelength can be focused on the retina but not perceived by the eye. As a result, the retina can be damaged in the same manner as with visible light even though the beam itself is invisible.

**Table 5.** Biological effect of wavelength on the various ocular tissue.

| **Wavelength (nm)** | **Effect on the eye** | |
|---|---|---|
| 180 – 315<br>(UVB & UVC) | The cornea absorbs these wavelengths which may cause photokeratis (also called welder's flash), reddening, tearing, or conjunctival discharge. Photokeratis, which is a very painful eye condition, is a photochemical process that causes denaturation of the proteins in the cornea. However, this is only a temporary effect since corneal tissue regenerate very quickly. |  |
| 315 – 400 (UVA) | The lens absorbs these wavelengths. A photochemical process occurs which denaturates the proteins in the lens and results in formation of a cataract. This effect is cumulative and will occur after long exposure times. |  |
| 400 – 1,400<br>Visible & near-IR | The retina absorbs these wavelengths since the lens, cornea and vitrous fluid are all transparent to these wavelengths. However, the lens and cornea will increase the irradiance on the retina by up to 100,000 times. This may cause irreversible damage since the cells in the retina do not rejuvenate. However, note that in the visible spectral range the eye may be protected by the aversion response. |  |
| 1,400 – 10,000<br>Mid & far IR | The cornea absorbs the light at these wavelengths because of the high water content of the corneal tissues and tears. This causes an increase in temperature and subsequent denaturation of the proteins in the cornea resulting in formation of cataract (loss of transparency) or producing surface irregularities. |  |

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## 4.2 Beam Hazard - Skin

Laser radiation injury to the skin is normally considered less serious than injury to the eye, since functional loss of the eye is more debilitating than damage to the skin. However, the chance for skin exposure from lasers is greater due to the skin's greater surface area compared to the eye. The layers of the skin that are of concern are the epidermis and the dermis. The epidermis layer is the outermost living layer of the skin, while the dermis mostly consists of connective tissue and lies beneath the epidermis. Figure 6 illustrates the cross-section of human skin.

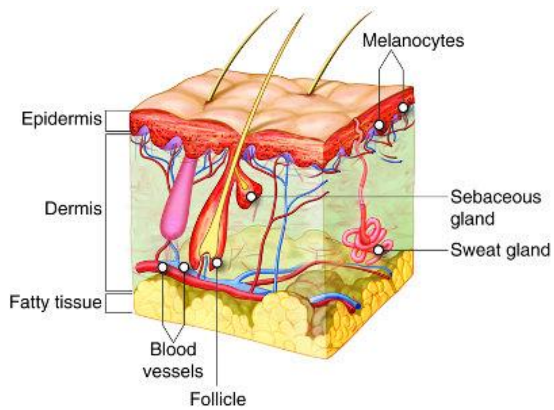


**Figure 6.** Cross-section of human skin.

As a result, inadvertent laser exposure in the lab can result in significant injury. Different wavelengths of the light spectrum penetrate to different depths of the skin (see Figure 7), the most penetrating being from visible and near infrared spectral regions (700 - 1400 nm). It is possible to have a painful injury from a severe laser burn, but most skin injuries heal. Usually a sensation of heat to the exposed area will be noticed, preventing most injuries. The exceptions to this are some high-powered lasers in the far-infrared range. Infrared lasers can cause thermal burns and blistering or charring of the skin as the incident radiation is converted to heat that is not dissipated rapidly enough due to poor thermal conductivity of the tissue. The UV-B range of lasers can be the most injurious, resulting not only in thermal damage but possibly in skin ageing and carcinogenesis. UV-A can cause hyperpigmentation and erythema. UV-C seems to have the least effect on the skin due to its short wavelength which is absorbed by the epidermis. Table 6 outlines the effect of light on tissue.

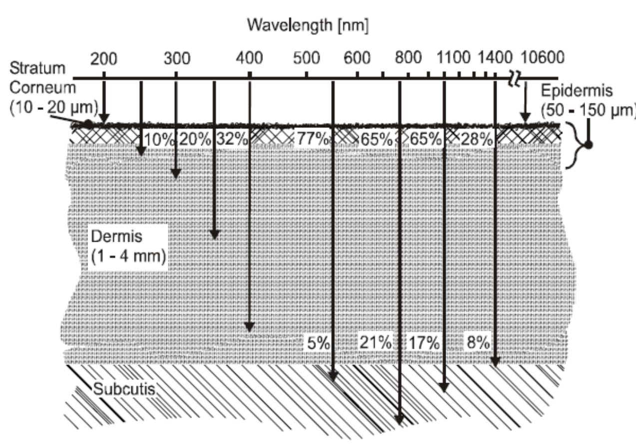


**Figure 7.** Skin penetration depth of various wavelengths.

**Table 6.** Biological effect of wavelength on the skin tissue.

| Wavelength (nm) | Effect on the skin |
|---|---|
| 180 – 280 (UVC) | Erythema (sunburn)<br>Skin cancer |
| 280 – 315 (UVB) | Erythema (sunburn)<br>Skin cancer<br>Accelerated skin ageing<br>Increased pigmentation<br>Skin burn |
| 315 – 400 (UVA) | Pigment darkening of the skin<br>Skin burn |
| 400 – 700<br>Visible & near-IR | Photosensitive reaction<br>Skin burn |
| 700 – 10,000<br>(infrared) | Skin burn |

The thermal damage process (burns) is generally associated with lasers operating at exposure times greater than 10 microseconds and in the wavelength region from the near UV to the far infrared. Tissue damage may also be caused by thermally-induced acoustic waves following exposures to sub-microsecond laser exposures. Biological damage induced by repetitively pulsed or scanning lasers is primarily a thermal process where the effects of the pulses are additive. The principal thermal effects of laser exposure depend upon the following factors:

- Irradiance or radiant exposure of the laser beam along with the absorption and scattering coefficients of the tissues at the laser wavelength;
- Duration of the exposure and pulse repetition characteristics, where applicable;
- Extent of the local vascular flow (as blood flow will help distribute the heat);
- Size of the area irradiated.

# 5. Non-Beam Hazards

Non-beam hazards (NBH) are all hazards arising from the presence of a laser system excluding human exposure to direct or scattered laser radiation covered above in beam hazards section.

While beam hazards (exposure to the laser beam) are the most noticeable laser hazards, other hazards pose an equal or possibly greater risk of injury or death. Some NBH can be life threatening (e.g. electrocution) and may require the use of more stringent control measures than those for beam hazards.

The list of associated NBH can be broken down into hazard categories: physical, chemical, biological, mechanical, and ergonomic human factors. Table 7 below shows examples of NBH.

Physical, chemical, and biological agents may occur when a material is exposed to a laser beam (e.g. fire or airborne contaminants), when materials used to generate the beam (e.g. flow- through gases, dyes and solvents) are released into the atmosphere, or when individuals touch the system components (e.g. shock or electrocution). The users don’t need to be experts in these areas, but they need to be aware that such hazards exist and be alert for them. Once the particular NBH is determined, the appropriate safety specialist from HSE will assist in performing a proper evaluation of the risks and set appropriate control measures.

**Table 7.** Examples of non-beam hazards (NBH).

| **Physical Hazard** | **Example** |
|---|---|
| Noise | Constant pinging of pulse laser |
| Pressure | Vacuum chamber, gas cylinders |
| Incoherent radiation | Broadband light source (e.g. flash lamps) |
| X-rays | Target interaction from metallic materials |
| High temperature | Ovens in lab |
| Low temperature | Cryogenic use for cooling system |
| Electricity | Power supplies |
| **Chemical Hazard** | **Example** |
| Toxic substances | Laser dyes |
| Carcinogenic substances | Solvents used with laser dyes or as cleaning agents for optics |
| **Irritant substances** | **Example** |
| Dust and particulates | Crack optics or Laser Generated Airborne Contaminant (LGAC) |
| Fire | From ignition (e.g. power supply or target interaction) |
| **Biological Hazards** | **Example** |
| Microbiological organism | From target interaction |
| Viruses | Released from target interactions |
| **Mechanical Hazards** | **Example** |
| Trailing cables and pipes | Housekeeping |
| Sharp edges | Razor blades |
| Moving parts | Robotic arm or piston |
| High-pressure water | Cooling lines |
| **Ergonomic Hazard** | **Example** |
| Workstation layout | Hitting head on table shelves |
| Manual handling | Lifting of lasers |
| Person–machine interface | Robotic work |
| Shift patterns | Working too many hours (fatigue, inattention) |

## 5.1 Electrical hazards

The number one associated hazard with laser use is the possible electrical hazard. Laser systems include a substantial amount of electrical equipment and related high voltage supplies. Precautions should therefore be taken to minimize the risk of electrocution and other laser-related electrical accidents. These exposures can occur during laser set-up, installation, maintenance and servicing, where equipment protective covers are often removed to allow access to active components. The effect can range from a minor tingle to serious personal injury or death. Another particular hazard comes from high voltage electrical supplies and capacitors that are often located close to cooling water pumps, lines, filters, etc. In the event of a spill or hose rupture, an extremely dangerous situation may result. During times of high humidity, over-cooling can lead to condensation which can have similar effects. Staff working with energized electrical equipment are recommended to complete electrical safety training.

Staff working with lasers should follow the safety precautions detailed below in order to prevent electrical shocks:

- Exposed liquids should not be used or placed near the laser system;
- Proper grounding should be used for metal parts of the laser system;
- All electrical equipment should be treated as if it were "live";
- Assume that all floors are conductive when working with high voltage;
- Do not work alone;
- Avoid wearing rings, metallic watchbands and other metallic objects;
- Only use one hand when working on a live circuits;
- Contact with electrical components should be avoided including capacitors that can contain electrical charge even after the laser is powered off. Check that each capacitor is discharged, shorted and grounded before allowing access to the capacitor area;
- Inspect capacitor containers for damages or leaks;
- Use, if possible, safety devices such as grounding sticks, insulating mats and appropriate rubber gloves.

## 5.2 Fire Hazards

A fire can occur when a laser beam (only Class 4, direct or reflected beam) strikes a combustible material such as paper, plastic, rubber, cardboard boxes, human tissues, human hair, and flammable liquids. Other potential fire hazards include electrical components and the flammability of Class 4 laser beam enclosure materials.

Staff working with Class 4 laser should follow the safety precautions below in order to prevent fire hazards:

- Use only fire resistant materials near direct and scattered laser beams from Class 4 lasers;
- Make sure the laser beam does not reach combustible items;
- Maintain precise control of the laser beam;
- Eliminate surfaces that can reflect laser beam;
- Fire extinguisher ($CO_2$ in particular) must be available near the Class 4 laser system.

## 5.3 Laser Generated Air Contaminant (LGAC)

Air contaminants may be generated when certain Class 3B and Class 4 laser beams interact with matter. Whether contaminants are generated depends greatly upon the composition of the target material and the beam irradiance. When the irradiance reaches approximately $10^7\ W{\cdot}cm^{-2}$ (Watt per square centimeter) target materials including plastics, composites, metals, and tissues may liberate carcinogenic, toxic and noxious airborne contaminants. HSE will assist in evaluating this potential industrial hygiene hazard.

Special optical materials used for far infrared windows and lenses are also sources of potentially hazardous levels of airborne contaminants. For example, calcium telluride and zinc telluride will burn in the presence of oxygen when beam irradiance limits are exceeded. Exposure to cadmium oxide, tellurium and tellurium hexafluoride should also be controlled.

Exposure to these contaminants must be controlled to reduce exposure below acceptable to KAUST Occupational Exposure Limits (OELs). The safety data sheet (SDS) for these materials should be consulted to determine exposure information and permissible exposure limits.

In general, there are three major control measures available:

- **Exhaust ventilation -** including use of fume hoods, should be used to control airborne contaminants;
- **Respiratory protection -** may be used to control brief exposures, or as an interim control measure until other administrative or engineering controls are implemented. Use of respirators must comply with the University Policy on Respiratory Protection. Contact the Research Safety Team (RST) or Laser Safety Officer (LSO) if you think a respirator is needed;
- **Isolation of the process -** the laser process may be isolated by physical barriers, master-slave manipulators, or remote control apparatus. This is particularly useful for laser welding or cutting of targets such as plastics, biological material, coated metals, and composite substrates.

## 5.4 Chemical Hazards

In some laser systems, dyes are used as the optical active medium. Laser dyes are often toxic, carcinogenic, and/or corrosive chemicals that are dissolved in flammable solvents. This creates the potential for personal chemical exposures, fires and hazardous spills. The most hazardous aspect of a laser operation is the mixing of chemicals that make up the laser dye. A safety data sheet (SDS) should accompany any chemical handled in the laser laboratory. The SDS will supply appropriate information pertaining to the toxicity, personal protective equipment needed and storage requirements of hazardous chemicals. In addition written safety instruction for handling these chemicals should be available in the lab.

## 5.5 Hazardous Gases

Hazardous gases may be used in laser applications; for example, excimer lasers use fluorine and hydrogen chloride. The laser lab must comply with KAUST compressed gases policy and standards such as cylinder restraints, use of gas cabinets, regulators rated for the type of gas to be used, relief valve settings, and proper tubing and fittings. See KAUST compressed gas safety program.

## 5.6 Cryogenic Fluid Hazard

Cryogenic fluids are used in cooling systems of certain lasers and can create hazardous situations. As these materials evaporate, they can replace the oxygen in the air, thereby creating oxygen deficient atmospheres (asphyxiation hazard). Adequate ventilation must be provided. Cryogenic fluids are potentially explosive when ice collects in valves or connectors that are not specifically designed for use with cryogenic fluids. Condensation of oxygen in liquid nitrogen presents a serious explosion hazard if the liquid oxygen comes in contact with any organic material. While the quantities of liquid nitrogen employed are usually small, protective clothing and face shields must be used to prevent freeze burns to the skin and eyes. Staff working with cryogenic fluids is recommended to complete cryogenic and liquid nitrogen safety training.

## 5.7 Explosive Hazard

High-pressure arc lamps, filament lamps, and capacitors may explode violently if they fail during operation. These components are to be enclosed in a housing that can withstand the maximum explosive force that may be produced. Laser targets and some optical components also may shatter if heat cannot be dissipated quickly enough. Consequently, care must be used to provide adequate mechanical shielding when exposing brittle materials to high intensity lasers.

## 5.8 Other Hazards

Excessive noise from high powered systems, emission of X-ray radiation, and other Non-Ionizing Radiation (NIR) sources from high-voltage power supplies may also be hazardous.

For example, laser discharge tubes and pump lamps may generate ultraviolet and visible radiation. The levels produced may exceed safe limits thus causing skin and eye damage. In addition, X-rays may be produced from two main sources: high voltage vacuum tubes of laser power supplies, such as rectifiers and thyratrons, and electric discharge lasers. Any power supply that requires more than 15 kilovolts may produce enough X-rays to be a health concern.

Interactions between very high power laser beams and target materials may produce plasma radiation (the complete dissociation of nuclei and orbital electrons). The plasma generated may contain hazardous blue light and UV emissions which can be an eye and/or skin hazard. When targets are heated to very high temperatures (e.g. laser welding and cutting) an intense light is emitted. This light often contains large amounts of short wavelengths, or blue light, which may cause conjunctivitis, photochemical damage to the retina or erythema (sunburn-like reactions) to the skin.

## Document History

| REV | DATE | PREPARED BY | DESCRIPTION |
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