

## GUIDANCE NOTE 9

### LASER SAFETY

#### 1. CLASSIFICATION OF LASERS

The basic approach to virtually all laser safety standards has been to classify lasers by their hazard potential, based upon their optical emission. According to *AS/NZS 2211.1 Laser Safety Part 1: Equipment classification requirements and users guide*, the manufacturer of lasers and laser products is required to certify that the laser is designated as one of six general classes, or risk categories, and label it accordingly. This allows the use of standardised safety measures to reduce or eliminate accidents depending on the class of the laser or laser system being used.

The following is a brief description of the six categories of lasers:

- **Class 1**

A Class 1 laser is considered safe based upon current medical knowledge. Under normal operating conditions Class 1 lasers or laser systems cannot produce a hazard and no safety measures are required. A Class 1 laser could also be a higher-class laser that is completely enclosed to prevent personnel exposure to the laser beam.

- **Class 2**

A Class 2 laser or laser system is defined as operating in the visible region (400-700nm). These lasers are not inherently safe but protection against eye damage will normally be afforded by aversion responses including the blink reflex. Momentary viewing (exposure of 0.25 second or less) is not considered hazardous. Intentional extended viewing, however, is considered hazardous.

- **Class 3**

Class 3 lasers are medium-power lasers that pose a modest potential for injury. Class 3 laser users may be required to follow specific safety precautions and may require the wearing of safety equipment such as laser protective eye wear. Skin hazards normally do not exist for incidental exposures. Three Class 3 sub-categories exist:

- **Class 3A**

A Class 3A laser emits higher levels of radiation and requires more stringent precautions than those necessary for Class 2 laser products. They differ from Class 2 laser products in that they emit more power in a beam of larger cross-section, so that when the output is viewed directly, the power of the beam entering the eye does not exceed that of a Class 2 laser product. However, if the beam is viewed through larger diameter collecting optics (eg. binoculars) then the hazard is usually increased. For continuous wave (CW) output in the visible wavelength range, the output power from Class 3A lasers is limited to 5mW and the maximum irradiance (power density) is  $25\text{W}\cdot\text{m}^{-2}$ .

- **Class 3B (Restricted)**

Class 3B (Restricted) lasers or laser systems operate at the same power levels as Class 3A but have higher levels (25 to 50W.m<sup>-2</sup>) of irradiance. They may be used in daylight conditions under the same controls as for Class 3A laser products. Where used in conditions of less illuminance (generally less than 10 lux), the appropriate safety controls are those specified for Class 3B laser products.

- **Class 3B**

Class 3B lasers can emit either invisible or visible radiation and direct viewing is hazardous to the eye. Class 3B lasers are capable of causing eye injury either because their output is invisible and therefore aversion responses are not activated, or because the beam power is such that damage is done in a time shorter than the blink reflex (0.25s). Higher power lasers in this class may also cause skin burns. However, with laser wavelengths other than those in the ultraviolet region, the pain produced by rapid heating of the skin will usually evoke an aversion response sufficient to avoid such burns.

- **Class 4**

Class 4 lasers are high-power lasers that pose a serious potential for injury of the eye and skin and require that users follow specific safety precautions and wear laser protective eyewear. They may operate in any part of the spectrum, as with the 3B. Class 4 laser systems can produce a hazard not only from direct or specular reflections, but also from a diffuse reflection. A fire risk may also be associated with the use of such high powered systems and their use requires extreme caution.

Of these classifications, only Class 4 lasers are incorporated into systems used for materials processing such as cutting, heat treatment, surfacing and welding. A Class 4 laser may be part of a system designed in such a manner as to be considered a Class 1 laser system. Such a system cannot under normal operating conditions, produce a hazard. This can be achieved using engineering controls such as enclosures, interlocks, and other mechanisms.

It is the duty of the manufacturer of the laser to classify the product and consequently to place warning labels on the product and to realise safety features such as key-locks and interlock connectors. However, if the user manipulates the laser product so that the class is changed, the user becomes responsible for a re-classification.

## 2. SAFETY WITH INDUSTRIAL LASERS (BEAM & NON-BEAM HAZARDS)

Potential hazards related to the use of lasers can generally be divided into primary and secondary hazards. The laser beam itself represents the primary potential hazard, as it can affect humans or objects – in the form of raw beam, focussed beam, directly reflected beam, or scattered radiation.

Secondary potential hazards are further subdivided into direct and indirect hazards:

- direct potential hazards are caused by technical components of the laser installation (high voltage, excitation radiation, laser gases, optics),
- indirect potential hazards are generated by the interaction of the laser beam with materials or the atmosphere.

Indirect potential hazards include the UV-radiation caused by plasma formation, hazardous substances generated during material processing, and also potential ignition of explosive materials and the danger of fire.

The division of potential hazards is shown in Figure 1

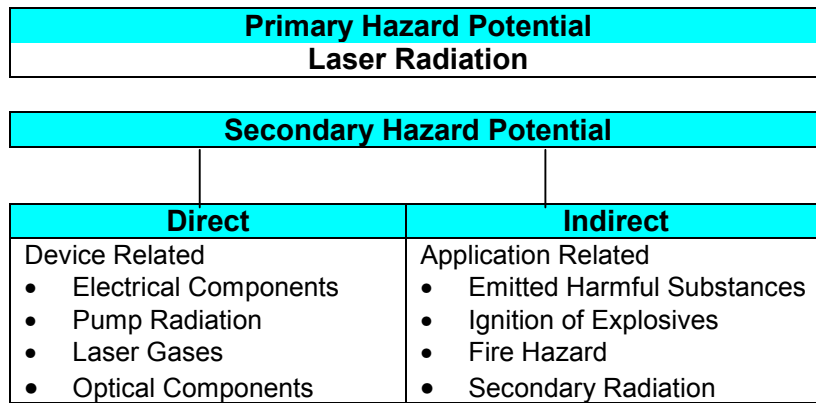


Figure 1. Hazards caused by laser material processing.

## 2.1 Laser Radiation

There are two potential dangers to personnel associated with laser radiation: eye and skin damage.

The factors that can contribute to tissue injury and influence the degree of damage from laser beam exposures include:

- a) Wavelength of laser radiation.
- b) Tissue spectral absorption, reflection and transmission.
- c) Strength of irradiance of incident laser beam.
- d) Size of irradiated area.
- e) Exposure duration.
- f) Pupil size.
- g) Location of retinal injury.
- h) Laser pulse characteristics.

Depending on wavelength, damage to either the cornea, the retina, or both, of the eye is possible. Exposure to radiation from a CO<sub>2</sub> laser (10.6 μm) typically results in corneal damage. The radiation from an Nd:YAG laser, at 1.06 μm, is much closer to the visible spectrum (400 to 700 nm) and can be transmitted by the cornea and lens. The lens will focus the laser light on the retina, causing severe and permanent damage to the retina and other intraocular material. This focusing, by the lens of the eye, can cause even low-power diffuse laser light to be focussed to a sufficient power density to cause retinal damage. Low-power helium-neon (He-Ne) lasers (0.633 μm), often used for alignment purposes, may also present a hazard.

Skin damage is restricted primarily to burns. It should be noted, however, for high-powered lasers these burns can be deep and cause severe and permanent damage.

The most effective prevention of injury is to ensure that the laser beam is encapsulated so that no human exposure can occur. For the case of an exposure to the beam, the level of exposure will determine if injury occurs. The level of exposure or irradiance which can be thought of as the border between safe and potentially harmful is called "Maximum Permissible Exposure", MPE.

The area around a laser installation where the MPEs for the eye can be exceeded is called the "Nominal Ocular Hazard Area", NOHA. The corresponding distance from the laser exit aperture is called the "Nominal Ocular Hazard Distance", NOHD. The NOHD depends on the laser power, geometrical

laser beam parameters such as the divergence, and the MPE. MPE values for the eye and the skin as a function of wavelength and exposure duration are listed in *AS/NZS 2211.1*. The standard also contains a number of sample NOHD calculations for a range of geometries and exposure situations.

As MPE and NOHD evaluations are quite complicated and involved, the laser classification scheme outlined earlier is used for the hazard evaluation process. For instance for Class 1 lasers, the exposure will always be below the MPE. Class 3 B lasers emit radiation which is significantly above the MPE for eye, and for Class 4 also above the MPE for the skin, however, it depends on the beam geometry, set-up and application, if this hazard exists only close to the exit aperture or if it extends over several kilometres.

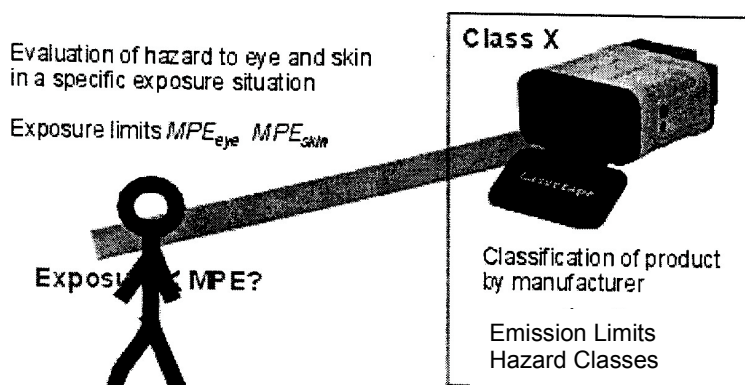


Figure 2. Comparison between a hazard evaluation of a given specific exposure scenario and the classification into hazard classes of products.

### 2.1.1 Eye Protection

Information on eye protectors suitable for use with particular lasers and operations together with their required marking is given in *BS EN207 Personal eye-protection. Filters and eye-protectors against laser radiation (laser eye-protectors)* and *BS EN208 Personal eye-protection. Eye-protectors for adjustment work on lasers and laser systems (laser adjustment eye-protectors)*.

The following should be considered when specifying suitable protective eyewear:

- a) Wavelength(s) of operation.
- b) Radiant exposure or irradiance.
- c) Maximum permissible exposure (MPE).
- d) Optical density of eyewear at laser output wavelength.
- e) Visible light transmission.
- f) Radiant exposure or irradiance at which damage to eyewear occurs.
- g) Need for prescription glasses.
- h) Comfort and ventilation.
- i) Degradation or modification of absorbing media, even if temporary or transient.
- j) Strength of materials (resistance to shock).
- k) Peripheral vision requirements.
- l) Any relevant legislation.

A method of selecting the laser or laser adjustment eye protector most suited to the hazards associated with the use of a particular laser is given in *AS/NZS 1336 Recommended practices for occupational eye protection*.

Special attention has to be given to the resistance and stability against laser radiation when choosing eyewear for Class 4 laser products.

Laser eye protectors and laser adjustment eye protectors which have been damaged or have undergone a colour change must not be used. Eye protectors are only intended to protect against accidental exposure as the ratings are based on a maximum exposure of 10s (for a continuous wave laser) or 100 pulses (for a pulsed laser). Eye protectors are not intended to be used for looking directly into the beam.

A precaution must be added here – standard safety glasses alone do not provide protection. Any laser eyewear, plain or prescription, **must** be labelled in accordance with *BS EN207* or *BS EN208* with information adequate to ensure the proper choice of eyewear with particular lasers. In some laser systems, ultraviolet light may be leaked into the workplace. Thus the eyewear should provide primary beam protection, secondary radiation protection and also ultraviolet protection.

### **2.1.2 Skin protection**

Where personnel may be exposed to levels of radiation that exceed the MPE for the skin, suitable clothing should be worn. Class 4 laser products present a potential fire hazard and protective clothing worn should be made from a suitable flame and heat-resisting material.

Special attention must be given to resistance and long-term stability against laser radiation when choosing protective clothing for use with Class 4 laser products.

## **2.2 Electrical Hazards**

The voltages used in lasers are sufficient to cause fatal injuries to personnel and account for most laser-related fatalities. All electrical equipment associated with laser beam materials processing should be installed in conformance to *AS/NZS 3000 Electrical installations* (known as the Australian / New Zealand Wiring Rules).

All doors and access panels should be properly secured, either electrically or mechanically, to prevent access by unauthorised personnel to electrical components, especially those operating at the laser excitation potential. All personnel working on or around high-voltage components should be trained in the proper safety techniques for electrical systems, as well as in the technique of removing a victim from an electrical circuit and administering cardiopulmonary resuscitation (CPR). Personnel should be aware of and adhere to any additional electrical safety requirements of the laser system installed in their facility. Usually, the best source of safety information is provided in the instruction manual from the manufacturer of the laser system. Always read, understand and follow the manufacturer's recommended safety procedures.

## **2.3 Fumes and Gases**

Welding, cutting and drilling, and surface modification with lasers may result in the generation of fumes, dust, and gases that can be hazardous to personnel.

These airborne contaminants may include:

- a) Vapourised target material and reaction products in the form of metal particles and oxides.

- b) Gases from the flowing gas laser systems or from the by-products of laser reactions, such as ozone, nitrous oxide, carbon monoxide and carbon dioxide.
- c) Gases or vapours from cryogenic coolants.
- d) Gases used to assist laser-target interactions, such as oxygen.

The hazards associated with welding and cutting of metals have been documented in a variety of publications including the WTIA Fume Minimisation Guidelines. It should be noted that some organic materials, such as plastics, can generate fumes that are hazardous. Care should be taken to avoid the excessive build-up of laser discharge gases, shielding gases, and assist gases, especially in enclosed spaces where oxygen can be displaced.

All necessary environmental engineering measures for fume and gas control (external venting, filtering, etc) should be taken to prevent the accidental inhalation of harmful concentrations of fumes and gases by personnel working on or around laser materials processing equipment. Exhaust of these fumes may violate local or federal standards, and implications should be considered before using equipment. The possible toxicity of the workpiece and consumables (wire, powder, etc) should be determined before laser beam materials processing begins. Adequate protection to personnel should be provided – refer to *WTIA Technical Note 7 Health and Safety in Welding* and the *WTIA Fume Minimisation Guidelines*. Also, for all materials, the Material Safety Data Sheet (MSDS), available from the material supplier, should be consulted to determine what hazards exist.

#### **2.4 Fire Hazard**

Since the laser system produces a very small spot size with high energy, the hazard of fire is present if the beam hits flammable material. Keep flammables away from the welding or cutting area. Be sure to cover and protect anything flammable in the area since reflected radiation could start fires in unexpected areas.

The potential for explosions at the capacitor bank or optical pump systems exists during the operation of some high-power laser systems. Metallic and non-metallic dusts such as airborne particles coming from the target area in the laser cutting, drilling and welding operations may be capable of causing fire or explosion. Explosive reactions of chemical laser reagents or other chemicals or gases are also possible.

#### **2.5 Secondary Radiation Hazards**

Viewing of the visible radiation emitted during laser materials processing can also be harmful to eyesight. During welding, a bright plume, similar in appearance to a welding arc, is generated from the interaction between the laser beam and material being processed. The size and intensity of this plume is a function of the material being processed, the power level, and the shielding gas used. Consequently, no exact guidelines can be given. However, the radiation emitted is broad-band, from the ultraviolet, which can cause sunburn and arc eye through the visible to the infrared, which can contribute to the formation of cataracts.

As the plume is generally too bright for direct viewing, adequate filtering, such as welding shades, should be employed for eye protection. As a general guideline, the filter used should be of sufficient optical density to ensure the viewer's comfort at the highest level of light intensity encountered and there should be no evidence of eye irritation after exposure. The optical viewing system should provide filtering in conformance to AS/NZS 1337 and 1338 and should include

provisions for filtering the visible and ultraviolet radiation from the plume as well as the laser radiation. All persons involved with laser beam materials processing should be instructed in the use of proper optical filtering and should be required to use such protection.

## 2.6 Optical fibre system associated hazards

There are many Nd:YAG lasers on the market now where fibre beam delivery is the only method of energy delivery. The optical fibre alone should not be relied on as a safe enclosure. Hazardous situations associated with the optical fibre itself include:

- Leakage due to inappropriate acceptance angle.
- Leakage due to the fibre being subject to too tight a bending radius.
- Fibre breakage due to excessive bending or twisting. If the fibre is carrying laser power at the time the break occurs then, because of the relatively small fibre diameter, the laser beam will emerge from what is effectively a high intensity point source as a divergent beam.
- Leakage and excess heat generation due to the ingress of dirt or other contamination onto the fibre input or output faces.

## 3. CONTROL MEASURES FOR LASER INSTALLATIONS

Laser systems used for materials processing can cause injury from both the direct beam or its specular reflections and from diffuse reflections. They also present associated hazards as outlined above. The following control measures should be employed to minimise these risks:

- a) The laser should only be operated in a controlled area. Class 4 lasers should be operated by remote control, whenever practicable, thus eliminating the need for personnel to be physically present in the laser environment.
- b) The entrances to areas should be posted with a standard laser warning sign as specified in AS/NZS 2211.1.
- c) Beam paths should be enclosed whenever practicable. Access to the laser environment during laser operation should be limited to persons wearing proper laser protective eyewear and protective clothing.  
Beam paths should avoid work area where possible, and long sections of tubes should be mounted so that thermal expansion, vibration, and other sources of movements in them do not significantly affect the alignment of beam forming components.
- d) Good room illumination is important in areas where laser eye protection is worn. Light-coloured diffuse wall surfaces help to achieve this condition.
- e) Fire, thermally induced aberrations in optical components and the melting or vaporisation of solid targets designed to contain the laser beam, are all potential hazards induced by the radiation of Class 4 lasers. A suitable beam stop should be provided. Materials which may be degraded by the beam must be avoided.
- f) Special precautions may be required to prevent unwanted reflections, especially for infrared laser radiation, and the beam and target area should be surrounded by a material opaque to the laser wavelength. (Even dull metal surfaces may become highly specular at the CO<sub>2</sub> wavelength of 10.6  $\mu$  m).  
Local screening should be used wherever practicable to reduce the extent of reflected radiation.
- g) The alignment of optical components in the path of a Class 4 laser beam should be initially and periodically checked.
- h) The remote interlock connector should be connected to an emergency master disconnect interlock or to room, door or fixture interlocks. The person in charge may be permitted momentary override of the remote interlock connector to allow access to other authorised persons if it is clearly evident that there is no optical radiation hazard at the time and point of entry.

- i) Laser systems not in use should be protected against unauthorised use by removal of the key of the key control.

#### **4. MEDICAL SURVEILLANCE**

Laser workers whose work involves a significant risk of exposure to laser radiation in excess of the Maximum Permissible Exposure (MPE) should have eye examinations and, where appropriate, skin examinations carried out at commencement and termination of the position.

For anyone at increased risk of laser damage, more frequent eye examinations may be prudent.

#### **5. LASER SAFETY OFFICER**

The “Laser Safety Officer” is defined in AS/NZS 2211.1 as “one who is competent in the evaluation and control of laser hazards and has responsibility for oversight of the control of laser hazards”.

For each organisation using potentially harmful laser systems, management should assign an individual to serve as LSO to be responsible for their safe use. The LSO requires this authority from management to ensure users maintain safe practices with their equipment. Management may employ an LSO to oversee the responsibility while relying on technical input from an outside expert. The LSO generally receives special safety training and has access to laser safety guidance documents, equipment and support staff commensurate with the extent of his or her responsibilities.

The LSO undertakes a risk assessment before a laser or laser system is first used, or after it has been modified. The LSO determines potentially hazardous areas, degree of hazard, necessary administrative and engineering controls, and necessary safety instructions, and determines appropriate personnel protective equipment such as optical density (OD) for laser protective eyewear. The LSO also maintains an inventory of lasers with detailed information such as: manufacturer, model number, quantity, physical location, user organisation, laser active medium, laser radiant power or energy, laser radiant wavelength(s), laser application, and laser hazard category. Other useful information (eg history and last maintenance date) may be required by an individual LSO.

#### **6. BIBLIOGRAPHY**

##### **a) References referred to in the text:**

AS/NZS 1336 Recommended practices for occupational eye protection.

AS/NZS 2211.1 Laser Safety Part 1: Equipment classification requirements and users guide.

AS/NZS 3000 Electrical installations (known as the Australian / New Zealand Wiring Rules).

BS EN207 Personal eye-protection. Filters and eye-protectors against laser radiation (laser eye-protectors).

BS EN208 Personal eye-protection. Eye-protectors for adjustment work on lasers and laser systems (laser adjustment eye-protectors).

WTIA Technical Note 7 Health and Safety in Welding.

WTIA Fume Minimisation Guidelines.

**b) Other references:**

ANSI/AWS C7.2:1998 Recommended Practices for Laser Beam Welding, Cutting, and Drilling.

Laser Institute of America (LIA). Laser Materials Handbook.

AWS Fact Sheet No.19. Laser Beam Welding and Cutting Safety.

Handbook on Industrial Laser Safety. K.Schröder (ed.), ARGELAS.

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