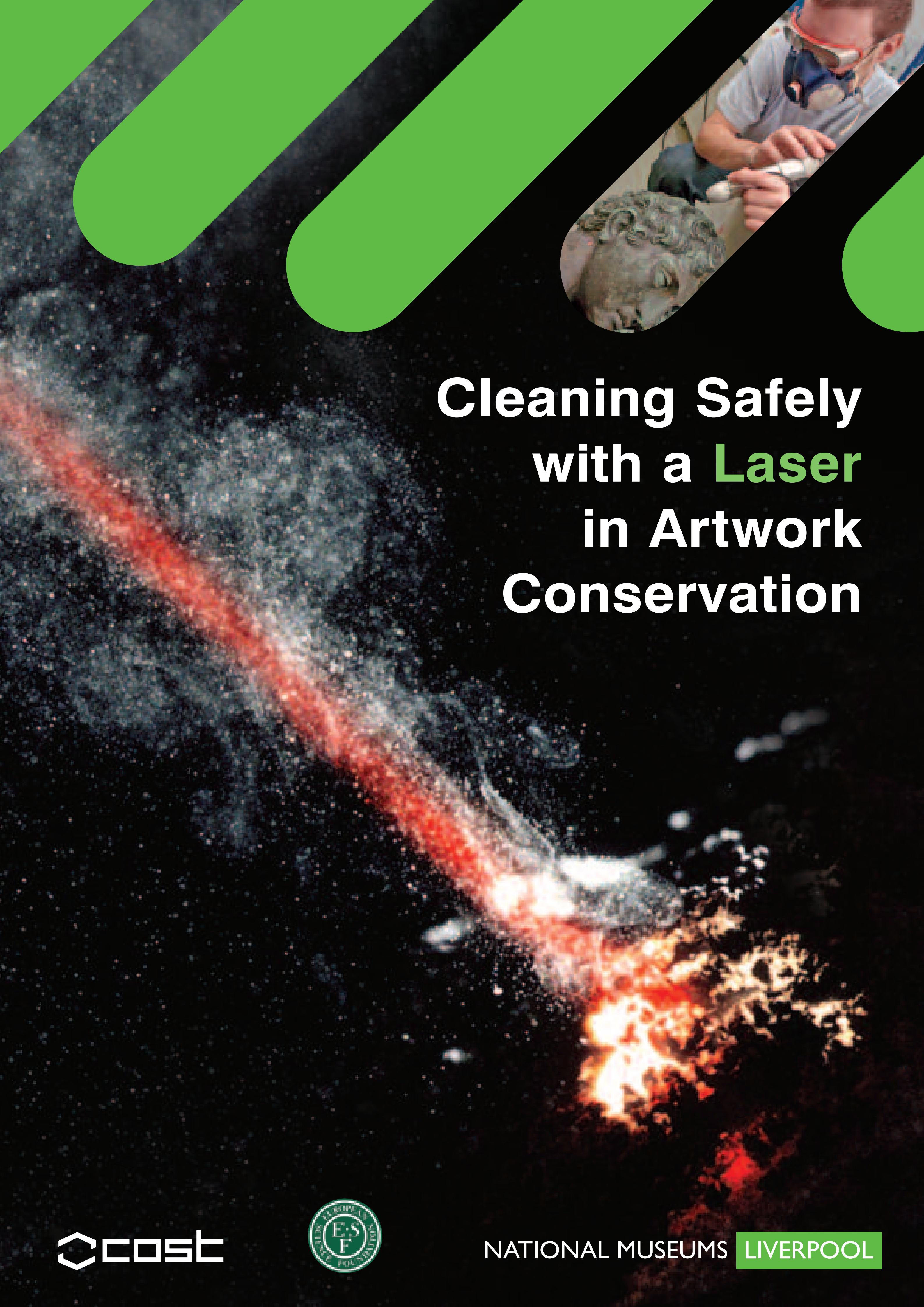

Cleaning Safely with a Laser in Artwork Conservation

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Cleaning Safely with a Laser in Artwork Conservation

Front cover: main photo showing removal of material during laser cleaning, reproduced by kind permission LRMH/Dominique Bouchardon ©

Introduction

Although laser safety within the European Union is covered by a common standard, **EN 60825-1 (Safety of laser products part 1; equipment classification, requirements and user's guide)**, we still lack specific adaptations of this standard to the field of cleaning of artworks. This booklet aims to fill this gap. Laser radiation is a unique form of light that can be utilised to clean delicate and valuable artworks in an extremely selective and controllable manner. The properties of laser radiation that make laser cleaning such a valuable technique for the conservator also give rise to hazards that must be properly controlled to ensure a safe working environment. For many conservators the implementation of the safety standard **EN 60825-1** can seem like a daunting prospect. This booklet aims to explain to those working with lasers in conservation how **EN 60825-1** can be implemented so that safe working practices are followed. It is important to note here the new user guidelines **IEC TR 60825-14 (Safety of laser products part 14: a user's guide)**, which gives advice to users on laser hazards, risk assessment and protective control measures. It is intended to replace the user guidelines in **EN 60825-1**, leaving the latter purely as a product compliance standard. The new guidelines have been published in the UK as **PD IEC TR 60825-14** but have not yet been adopted in Europe as some countries have their own national guidelines and requirements covering laser use.

This booklet has been put together by a group of experts, within the framework of the European network **COST G7 "Artwork Conservation by Laser"**. It is divided into six chapters: Chapter 1 deals with the basic principles of laser operation: it describes the properties of laser radiation and how a laser works; Chapter 2 describes the hazards associated with the laser cleaning process; Chapter 3 refers to laser system classification; Chapter 4 provides a general overview of the three groups of safety controls, which together form an effective health and safety framework: administration controls, engineering controls and personal protective equipment; Chapter 5 describes laser safety in a practical context: ensuring safety in and away from the conservation studio. Finally, the appendix (Chapter 6) contains useful additional information: glossary, description of common laser cleaning systems, introduction to quantitative hazard assessment, list of relevant safety standards and a list of sources of information.

1

Basic principles of laser operation

1.1 Properties of laser radiation

The term LASER was originally presented by Townes and Schawlow in 1958, in a publication describing the effect of Light Amplification by Stimulated Emission of Radiation. The importance of their discovery was acknowledged by the award of the Nobel prize for Physics. Pioneering work in the field of laser cleaning of artworks was carried out in Italy during the 1970s by John Asmus, who used a pulsed ruby laser to selectively remove black encrustations from crumbling marble sculpture. This work was successful and expanded to look at the potential of laser radiation for cleaning a wide range of materials. However, at that time laser technology was expensive and largely undeveloped and it was not until almost twenty years later that it had reached a level of maturity for laser cleaning systems to become a reality in the field of artwork conservation. The use of laser cleaning is now most widespread in the field of sculpture conservation, where the versatile and reliable Nd:YAG laser has established a strong foothold. Laser cleaning in the fields of paintings, parchment, paper and textiles conservation is presently at a much earlier stage of development.

A laser is a device that produces a special form of light. A conventional light source, such as a light bulb, produces a diffuse form of light containing a broad range of wavelengths. A laser produces a much more structured form of light. Laser radiation is extremely bright (several orders of magnitude greater than the light we receive from the sun), has a high degree of purity (can be considered as a single wavelength) and is usually emitted in a very narrow beam. The divergence of a typical laser beam is only 1 mrad, i.e. the beam will spread out by only 10 cm after travelling 100 m. These properties mean that laser radiation is well-suited to the application of cleaning artworks. The purity of the beam means that selective removal of unwanted material is often possible, while its low divergence and high brightness allow the energy in the beam to be collected by a lens and focused to achieve the power and energy densities necessary to remove material from a surface.

The wavelength of laser radiation is a property of the selected laser (some examples are given in table 1). The early work of Asmus and colleagues was carried out using a pulsed ruby laser emitting light in the red part of the visible spectrum. The majority of laser cleaning of sculpture is now carried out using the 1064 nm wavelength (infrared, IR) of the Nd:YAG laser, while the short ultraviolet (UV) wavelengths of the excimer laser have been used in the cleaning of paintings.

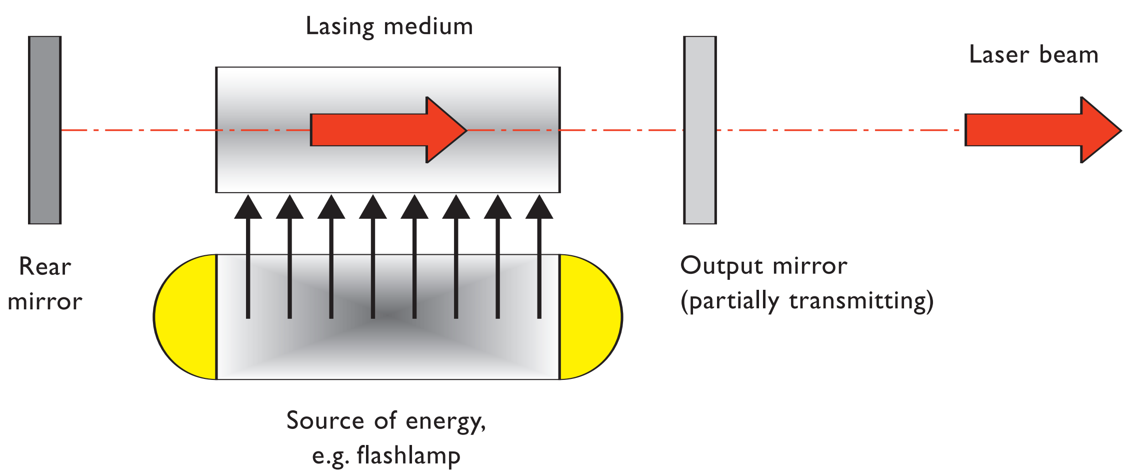
Laser type	Short form	Wavelength (nm)	Medium
Excimer	ArF	193 (UV)	Gas
	KrF	248 (UV)	
	XeCl	308 (UV)	
	XeF	351 (UV)	
Ruby	Cr: Al_2O_3	694 (visible)	Crystal
Neodymium YAG	Nd: YAG	1064 (IR)	Crystal
Erbium YAG	Er: YAG	2940 (IR)	Crystal
Carbon dioxide	CO_2	10600 (IR)	Gas

Table 1 Some laser emission wavelengths used in conservation.

1.2 Operation of a laser

Essentially, a laser is a device that converts electrical energy into an intense, pure beam of light. It consists of a lasing medium (may be a cylindrically shaped crystal or a gas column host in a tube), positioned between two highly reflective mirrors and a source of energy, known as the pumping source (figure 1). Most of the energy from the pumping source is absorbed by the lasing medium, which is raised to an excited energy state. The lasing medium returns to its initial stable state by producing light (the wavelength of which is determined by the energy levels of the medium participating in the process) via a process known as stimulated emission. Unlike the light from a conventional source, this light is coherent (highly ordered) and its intensity increases as it travels through the medium and is fed back by the mirrors at either end of the optical cavity. Only light travelling along the axis of the cavity is amplified, the result of which is generation of an intense, highly directional beam of light. Output of the laser beam is through the output mirror, which is made partially transmitting.

Figure 1 Schematic representation of a laser.

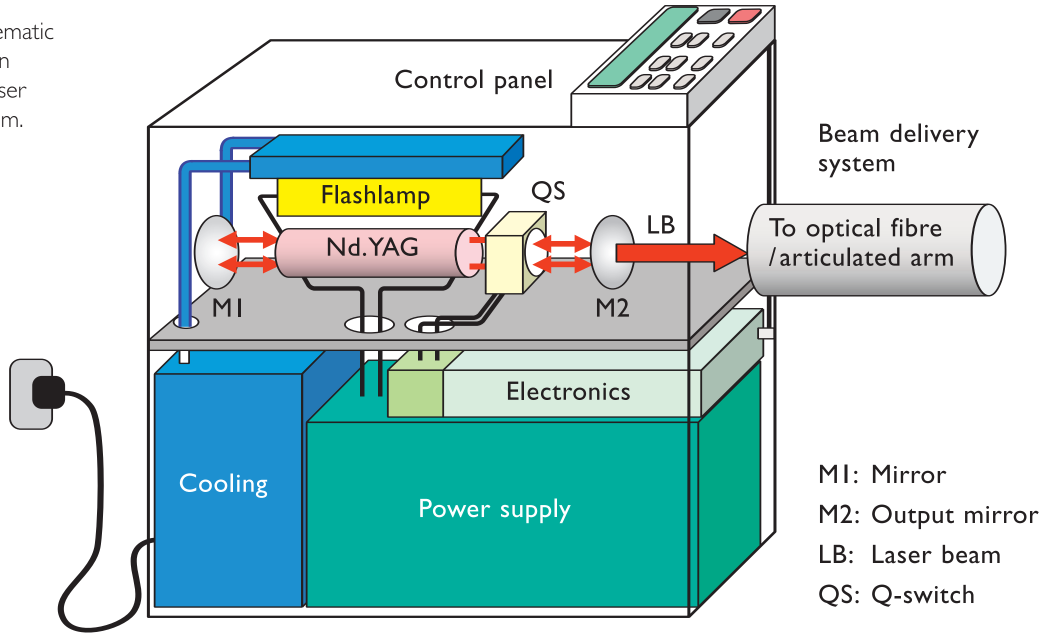


Light may be emitted from a laser in either continuous or pulsed form, depending on the nature of the pumping source. If the pumping source provides energy in a short burst (rather than in a continuous form) then the resulting emission is a pulse of light. The length of the pulse is determined by the duration of the burst of energy from the pumping source, e.g. several hundred microseconds (normal mode operation) for a flashlamp used in a Nd:YAG laser. A much shorter duration in the range of several nanoseconds (Q-switched mode) is obtained by inserting an extra device (Q-switch) between the lasing medium and one of the mirrors. Operation in an intermediate range of 30 ns - 50 µs can also be achieved.

1.3 Laser cleaning systems

A typical laser cleaning system will comprise a laser head (containing lasing medium, pumping source and mirrors), cooling system, power supply, control panel and beam delivery system. These are usually integrated into one unit, although some systems (e.g. high power lasers used for large-scale cleaning) may use a separate power supply and cooling unit. Various studies have separately developed laser instrumentation and cleaning procedures, which have been validated on a number of case studies. The most common laser cleaning systems presently employed in conservation are based on solid state lasers (e.g. Nd:YAG). Gas lasers (e.g. excimer) are often impractical for use in a conservation environment and their use is limited to a small number of highly specialised applications (e.g. removal of aged, discoloured varnish layers from a painting). Hence, the following refers to the Nd:YAG laser cleaning systems currently available. A schematic representation of a typical laser cleaning system is shown in figure 2.

Figure 2 Schematic representation of a typical laser cleaning system.



Laser head

The laser head consists of a flashlamp, Nd:YAG crystal and two mirrors forming the optical cavity (figure 2). Many systems incorporate a Q-switch within the laser cavity. Laser cleaning systems with harmonic generation (a process converting the fundamental wavelength of the laser output to a new wavelength) will also incorporate a non-linear crystal between the laser head and the output aperture of the system. The laser head is of a rugged design and is cooled by water flow.

Cooling system

De-ionised water is circulated around the laser head to remove heat produced during the lasing process. A small reservoir of water (several litres capacity) is usually contained within the laser cleaning system. Some systems, particularly high power lasers (building cleaning), may have a separate cooling unit.

Power supply

The power supply, which normally runs from a single phase mains electricity supply (high power lasers may have special requirements), provides the power to the flashlamp, cooling water pump, the Q-switch and the control unit.

Control unit

The operator usually has control over a number of laser parameters: pulse energy and pulse repetition rate, which are accessed via the control panel. A mechanical shutter, which allows the laser beam to exit the laser head and enter the beam delivery system is usually controlled by a footswitch or handswitch. A clearly visible and easily accessible 'emergency stop' button will turn the system off instantly. Laser cleaning systems should also incorporate suitable outlets for an external interlock and a warning light. Some systems (usually those with optical fibre beam delivery) will also have a remote control unit that allows control of these parameters away from the main body of the laser system.

Beam delivery

The laser beam is delivered to the workplace by an articulated arm (incorporating specially coated mirrors in the joints of the arm) or a flexible optical fibre. In general, the mirrors in an articulated arm have a higher damage threshold than optical fibres. This allows delivery of higher power pulses through an arm. An optical fibre is generally more flexible and allows work away from the main body of the laser, in less accessible areas (fibres may be as long as 40 m). Higher power lasers with fibre delivery use a number of fibres bundled together so that the laser energy is divided between the fibres. Some systems allow switching between the two forms of beam delivery.

Handpiece

The laser beam emerges through a handpiece, which is held by the operator. Lenses within the handpiece allow focusing of the laser beam and control of the energy density at the surface of the artwork. Many laser systems also incorporate an aiming beam (low power, continuous, visible laser beam), which allows careful targeting of the cleaning beam. The handpiece may also incorporate a switch to start/stop laser emission.

Some typical laser cleaning systems are shown in figure 3.

Figure 3 Typical laser cleaning systems used in conservation.

(a) Nd:YAG laser with optical fibre delivery

(height of main unit: 90 cm, ElEn Group, www.elengroup.com);

(b) Q-switched Nd:YAG laser cleaning system with articulated arm delivery

(height: 93 cm, Lynton Lasers Ltd., www.lynton.co.uk).

Hazards of laser cleaning systems

The unique properties of a laser beam give rise to certain hazards, which must be controlled to ensure safe working. Laser radiation entering the eye can cause permanent damage and the low divergence of a laser beam means that energy can be delivered over relatively large distances with very little change to its properties. A laser beam can therefore remain hazardous a long way from the source. In addition to hazards from the laser beam itself, hazards associated with use of the laser beam for cleaning also exist: ejection of particulates and vapours from the surface and noise generated by equipment and the cleaning process. The hazards associated with the use of laser cleaning systems in conservation are outlined here.

2.1 Laser beam hazards

2.1.1 Ocular hazards

The eye is an extremely sensitive and important part of the body. The ability of the eye to collect and focus light means that it is vulnerable to laser-induced damage. Damage can occur at all wavelengths, although the area of tissue affected is wavelength-dependent (table 2). Laser radiation emitted in the visible (400 - 700nm) and near infrared (700 - 1400nm) spectral regions poses the greatest risk as the light is transmitted effectively through the liquid in the eye and focused to an extremely small spot on the retina at the back of the eye (figure 4). This wavelength range is known as the retinal hazard region.

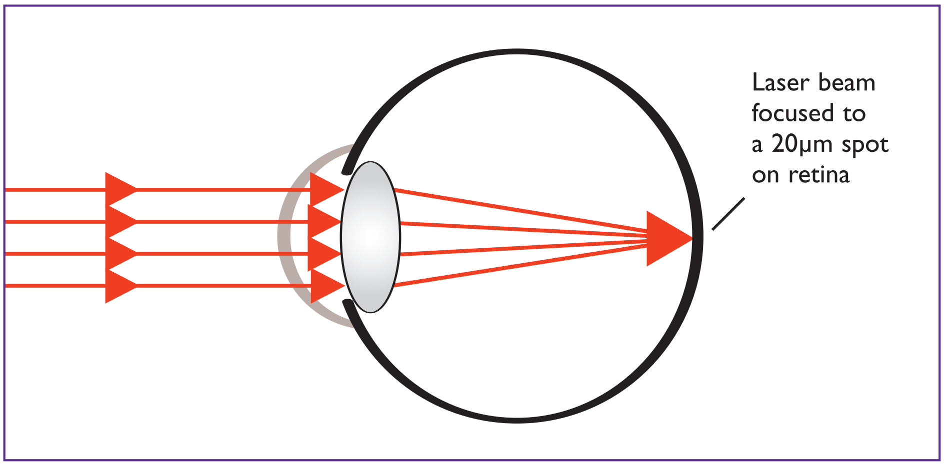


Figure 4 Schematic representation of a section through an eye. The cornea and lens of the eye focus the highly directional light in a laser beam to a very small spot on the retina, resulting in very high power densities. A conventional light source is usually imaged as an extended image with a correspondingly smaller power density on the retina.

This high concentration of energy can be sufficient to permanently damage the retina (figure 5). This damage can be especially serious if it occurs to the central region (fovea) of the retina, which contains a particularly high concentration of light sensors. Damage here can seriously affect the sight in that eye. Unfortunately, most accidents occur with the viewer looking in the direction from which the laser beam has travelled and damage to the eye is, therefore, most likely to occur in this critical region.

Laser radiation at short wavelengths (<300 nm) in the ultraviolet and at long wavelengths in the far infrared (>3000 nm) regions is absorbed at the front of the eye, which can cause damage to the cornea. Laser radiation in the middle infrared (1400 - 3000 nm) and near ultraviolet (300 - 400 nm) regions is absorbed mainly by the lens, which can lead to formation of a cataract. Even short exposures to a high intensity laser beam can cause damage. This is partly due to the fact that the duration of laser pulses used in cleaning applications (typically 10 ns) is extremely short compared to the time needed for protection afforded by the blink reflex (approximately 0.1 s). This means that injury can be caused by a single pulse.

An examination of laser accident records shows that the source of accidental ocular exposure is frequently a reflected beam. Laser cleaning systems in conservation are usually classified as class 4 products (see section 3 for explanantion). This means that viewing of a specular reflection (from a shiny surface, e.g. scalpel or scaffolding pole) and viewing of diffuse reflections of the beam (from a matt surface, e.g. pollution encrustation, stone surface) are both potentially hazardous.

In industry, laser processing is often carried out within an enclosed set-up so that the beam is confined to the immediate workplace and beam hazards are reduced to a minimum. However, in the field of artwork conservation, the laser beam is often hand-guided and can potentially travel over larger distances. Additional precautions (see section 4) are therefore necessary to confine the laser beam to a safe working area.

Table 2 Wavelength-dependence of laser damage to the eye.

Wavelength region	Part of eye susceptible to laser damage
Ultraviolet (<300 nm)	Cornea
Near ultraviolet (300 - 400 nm)	Lens
Visible (400 - 700 nm)	Retina
Near infrared (700 - 1400 nm)	Retina
Middle infrared (1400 - 3000 nm)	Lens
Far infrared (>3000 nm)	Cornea

Figure 5 Laser-induced damage to a human retina (dark spot, left of centre). Damage resulted in blindness in one eye for a laser operator with over 20 years' experience of working with lasers.

Photo reproduced by kind permission, Austrian Research Center Seibersdorf.

2.1.2 Skin hazards

Laser radiation can also cause injury to the skin, though in general skin hazards are considered to be less serious than eye hazards. The part of the skin affected will depend on the wavelength of the laser beam. Visible and near infrared (400 - 1400 nm) radiation is able to penetrate into the epidermis (50 - 150 μm from surface) and dermis (1 - 4 mm), whereas far ultraviolet and far infrared radiation is absorbed strongly in the stratum corneum (8 - 20 μm). Potential effects of irradiation of skin by a laser beam are summarised in table 3.

Table 3 Summary of the effects of a laser beam on skin.

Wavelength region	Skin effects
Ultraviolet (200 - 400 nm)	Erythema (sunburn) Skin cancer Accelerated skin ageing Increased pigmentation Pigment darkening Skin burn
Visible (400 - 780 nm)	Photosensitive reactions Skin burn
Infrared (780 - 10000 nm)	Skin burn

2.2 Debris generated during the cleaning process

Laser cleaning may involve evaporation, smoke-generating pyrolysis, melting, and/or spalling of the layer to be removed. These waste products are composed mainly of material removed from the substrate. In addition, small amounts of compounds that were not part of the original material, gases generated by thermal cracking of organic substances and their eventual combustion, can be created. These laser-generated air contaminants are known to create objectionable odours and visible smoke. Removal of some organic materials may release potentially harmful bacteria, fungae (hyphae and spores) into the vicinity. The human response to chemicals depends on several factors, including the type of chemical, its concentration and form, and the individual (age, sex, genetics, health, etc.). Some chemicals are irritants, some cause immune responses for allergic persons, and some can be the cause of disease after many years of exposure.

These potentially harmful fumes should be withdrawn from the breathing zone by extraction, but unfortunately this practice is not always undertaken. A recent investigation has shown that in a workshop of 50 m^2 floor space and 4 m height without any air exchange, 10 minutes laser cleaning of limestone was sufficient to reach the maximum permissible workplace concentration (MPWC) of breathable quartz dust. The MPWC for inhalable CaO and SO_2 from vaporised gypsum (a common mineral found within pollution crusts on outdoor sculpture and buildings) was attained after 10 to 20 minutes. Another study, also undertaken indoors, showed that the emitted debris resulting from the removal of sulphation crusts by laser cleaning included a significant proportion of particles with diameters of 3μm or less. Such small particles can penetrate the lungs down to the alveoles, and are potentially harmful by solubilization of their alkaline and metallic salt compounds. Such small particles are also able to enter the body through the skin. Information on the relationship between emitted particles and beam power, energy density, pulse frequency, degree of cleaning, and cleaning rate is still lacking for conservation. The situation is further complicated by the fact that the exact composition of the soiling layer being removed is often unknown.

2.3 Noise hazards

There are three sources of noise at laser cleaning workplaces: (i) the laser system itself, (ii) the fume extraction device, and (iii) the laser cleaning process. The rapid ejection of material from a surface during laser cleaning leads to the generation of sound waves, which propagate away from the surface and are heard as a 'snapping' sound. The long term effects of exposure to all three sources of noise together have not yet been investigated.

2.4 Electric and fire hazards

High voltage electrical equipment is often contained inside a laser. This does not normally pose a hazard unless the protective covers of the laser are removed. Extreme caution should be exercised during maintenance and servicing when the covers of the laser cleaning system may be removed. Maintenance and servicing of lasers should only be carried out by people who have received the appropriate training. Most laser cleaning systems use water in the cooling system, which would create a serious hazard if allowed to come into contact with the electrical equipment inside a laser. Under normal conditions, this will not happen but, of course, great care should be taken during maintenance and servicing. Fire hazards may be the consequence of electrical faults, or may be due to ignition of flammable materials by the laser beam, as reported in some medical applications.

3

Laser classification

A laser cleaning system, as with all devices incorporating a laser, is assigned to a product class according to the potential of its accessible laser emission for causing injury. These product classes are detailed in the European standard IEC 60825-1. It is the manufacturer's or supplier's responsibility to ensure that the cleaning system is correctly classified and that the requirements of the particular class (labels, other safety features etc.) are met. The product classes are outlined in table 4.

The classification of a laser product depends on the *accessible* laser emission. A product may be assigned to class 1 if its output power is too low to be considered hazardous, or if the engineering design of the product is such that it is not possible, under reasonably foreseeable conditions of use, to access the laser radiation. A class 4 laser may be embedded in a product, which is assigned to class 1, if the design of the product meets the safety requirements detailed in IEC 60825-1 (figure 6). Most laser cleaning systems used in conservation are class 4, i.e. their use requires extreme care. The type of laser radiation used to clean the surface of an artwork is unsafe and the nature of the work usually requires that the laser beam be delivered through a flexible handheld optical fibre or articulated arm (figure 7). It is important to note that modifications to a system may lead to a change to its classification and hence to the safety controls appropriate to its use. Maintenance work may also necessitate the implementation of additional safety controls.

Figure 6 Class 1 arrangement for laser cleaning. Laser cleaning, using a class 4 laser, is carried out within a glove box so that the laser beam is confined within the box.
Photo courtesy Laserblast, Quantel, France.

Figure 7 An example of a class 4 laser cleaning system. Output of the Nd:YAG laser beam in these cases is via a handheld pen fixed to the end of an articulated arm.
Photo courtesy Johann Nimmrichter, Bundesdenkmalamt Department of Conservation, Vienna.

Table 4 Summary of laser classification (for a full description see IEC 60825-1 or the equivalent national standard). Most laser cleaning systems are class 4.

Laser class	Explanation
1	Safe under reasonably foreseeable conditions of use.
1M	Same as for class 1, but unsafe if magnifying viewing instruments are used, e.g. telescopes, microscopes etc.
2	Safe for accidental brief viewing. Protection afforded by blink reflex of eye.
2M	Same as for class 2, but unsafe if magnifying viewing instruments are used.
3R	Unsafe for eye, but risk of injury low unless viewing prolonged.
3B	Direct viewing of the beam or specular reflections is hazardous. Viewing of diffuse reflections may be safe.
4	Unsafe. Viewing of the direct beam, specular reflections and diffuse reflections is hazardous. May also pose hazards to the skin and their use may create fume and fire hazards. Use requires extreme care.

Safety controls

In order to establish the precautions necessary for safe working with lasers it is necessary to identify the hazards and to establish the level of risk (a combination of the likelihood of harm occurring and the severity of injury that would result). This is achieved by way of a risk assessment (health and safety at work legislation requires that a risk assessment is carried out for all work-related hazards). The risk assessment will need to identify all hazards, establish the conditions under which these hazards may exist and identify the level of risk to which people may be exposed. Appropriate safety controls can then be put in place to reduce the level of risk to an acceptable level. Both the risk assessment and safety controls should be documented. There must be a formal written framework within which laser safety is managed by the organisation.

A Laser Safety Officer (LSO) should be appointed to take administrative responsibility of laser safety on behalf of the employer and to ensure compliance with safe working procedures. The role of the LSO includes ensuring appropriate control measures are in place, regular monitoring of laser hazards and the effectiveness of the control measures implemented and the maintenance of records of such monitoring. The employer retains overall responsibility for laser safety. The employer should ensure that the LSO has the knowledge and capability to carry out his role effectively. The LSO may need to call in a Laser Protection Adviser (LPA) in certain situations, e.g. establishing appropriate safety controls or where working conditions differ in some way from the normal situation. The LPA is an expert in laser safety. The LPA is defined in a new European document awaiting publication, CLC/TR 50448 (Guide to levels of competence required in laser safety). The role of the LSO should also include the specific approval of control measures. This is especially important with outdoor cleaning where the safety installation will be temporary and conditions may be far from ideal. The LSO should inspect and approve (or if necessary require changes and additions to) such installations before they can be used. Such approval should be documented.

Some organisations undertake basic eye tests of people before they start working with lasers. This is not a requirement of the safety standard EN 60825-1 (IEC TR 60825-14), and, if carried out, is normally carried out for medical-legal reasons. A procedure for dealing with laser-related accidents (including the reporting of such accidents) must be in place.

The safe use of laser cleaning systems in conservation requires adoption of a number of safety controls, governed largely by the classification of the system. These are divided into three main areas: administrative controls, engineering controls and personal protective equipment. Each of these areas is important and together they provide an effective means of ensuring laser safety. The controls outlined here should be implemented for a class 4 product (most laser cleaning systems currently in use in conservation are class 4). Please refer to EN 60825-1 (IEC TR 60825-14) for controls applicable to other classes.

4.1 Administrative controls

Administrative controls are concerned with controlling who uses the laser cleaning system and how it is used. The procedural aspects of the administrative controls, i.e. the 'local rules', are extremely important as these establish the organisational framework within which the laser will be used. A vital part of laser safety is hazard awareness and understanding of the procedures put in place to reduce the risk of injury to an acceptably low level. Use of a laser cleaning system should, therefore, be restricted to personnel who have received training in safe use of lasers. This training should be relevant, i.e. relate to use of a laser cleaning system in a conservation environment, and provide the user with a realistic understanding of the hazards associated with laser cleaning, of the operation of the equipment and the safety procedures adopted by the employer. Records of training should be kept. Access to the laser system should be controlled through a key or password entered via the control panel. Keys should be stored in a separate area from the cleaning system.

4.2 Engineering controls

Engineering controls are concerned with maintaining the laser beam within a 'controlled' area, making access to the 'controlled' area safe and use of equipment to remove by-products of the cleaning process from the work-area. Most laser cleaning systems produce a diverging laser beam (the rate at which it spreads out from the handpiece will depend on the type of lenses used within). As the laser beam travels away from the system, eventually it will spread out to such a large extent that it can be considered safe, i.e. it has become too weak to damage the eye. This distance is referred to as the Nominal Ocular Hazard Distance (NOHD). The NOHD is dependent on the characteristics of the laser cleaning system being used, including wavelength, pulse length, pulse energy and beam divergence. The NOHD for laser cleaning systems in conservation may range from tens of metres to hundreds of metres. Practically, this means that laser cleaning should be carried out within a controlled area, within which the laser beam is confined. Appropriate warning signs and a warning light (activated when the laser is in operation) should be clearly visible. Many systems also incorporate an audible warning which is activated when the laser fires. Interlocks should be installed at points of access to the controlled area so that the laser system is turned off when someone enters the area. When setting up a controlled area (either within a large studio or on-site), the path of a laser beam escaping from the area (if a roof has not been included) should always be considered: specularly reflecting surfaces (e.g. shiny metal pipes) may exist above the work area or windows in the upper floors of a neighbouring building may be directly in the line of sight. In such cases, the possibility exists of people outside the controlled area inadvertently being exposed to hazardous radiation and so a roof should be included (of course, this may also be necessary outside to provide protection from the weather). Special care should be taken on scaffolding to ensure gaps between scaffold boards are covered or filled, if work is taking place either above or below the laser cleaning area. Particulates and fumes generated by the cleaning process should be extracted at source.

4.3 Personal protective equipment

Figure 9 Safety eyewear and face mask being worn during laser cleaning work. The wearing of long sleeves and gloves would provide additional protection from fine particulates. In this case, efficient removal of ejected material from the work area via a local extraction system was considered sufficient.

Photo courtesy of National Museums Liverpool.

Figure 8 Protective eyewear is available as goggles (which fit over spectacles worn to correct eyesight) or spectacles. The type of lens and level of protection required will depend on the specifications of the laser being used including wavelength, pulse length, maximum pulse energy, repetition rate and beam divergence. Changing from work at one wavelength to another will usually require changing the protective eyewear also.

The use of personal protective equipment (PPE) is necessary where protection cannot be guaranteed by the implementation of appropriate administration and engineering controls alone, which is almost always the case in conservation. Since the direct laser beam and both specular and diffuse reflections generated from the surface of an artwork during laser cleaning are hazardous to the operator, PPE in the form of protective eyewear is essential. Such eyewear is available from specialist manufacturers in the form of spectacles or goggles (figures 8, 9). Eyewear must provide adequate protection at the wavelength being used (EN 207 covers laser protective eyewear); this means that changing the wavelength of the emitted beam will usually necessitate a change in protective eyewear. The protection level required is determined by the characteristics of the laser system being used: wavelength, pulse length, maximum pulse energy, maximum repetition rate and beam divergence. A specialist manufacturer or laser safety consultant will be able to calculate the level of protection required knowing the characteristics of the laser system being used and to advise on appropriate eyewear. Laser safety eyewear should be CE marked. The transmission of visible light should be as high as possible so that visibility is not impaired. Eyewear suitable for cleaning at 1064 nm has good transmission of visible light. However, eyewear suitable for cleaning at 532 nm (green) makes use of orange filters, which can significantly affect the visibility of the artwork. Eyewear should fit correctly and be worn by everyone within the controlled area (see section 4.2). Safety eyewear must not be used if damaged. It is also advisable to wear an appropriate facemask during cleaning to ensure that particulates and harmful vapours are not inhaled (figure 9). It is recommended to wear long sleeves and gloves to provide additional protection from fine particulates entering the body through the skin. Working at ultraviolet wavelengths may necessitate skin protection from the associated beam hazard.

5

Practical laser safety

In addition to the controls outlined in section 4 attention should be paid to other factors, such as avoiding exposure of skin, quality of illumination, presence of shiny surfaces, covering windows within a controlled area, number of people within the controlled area and general hygiene.

As discussed in section 2.1.2, laser radiation can pose a hazard to the skin. It is, therefore, important to avoid exposure of skin to the laser beam. At infrared wavelengths simple avoidance by careful aiming of the laser beam at the target is usually sufficient. Prolonged cleaning at ultraviolet wavelengths, however, may require protection of the skin from diffuse reflections.

The workplace should be well-illuminated. This allows the conservator to see the work properly (especially when wearing tinted eye protection), to move around the work area freely and see other hazards such as trailing cables. Ideally, the walls surrounding the workplace should be light coloured and diffusely reflecting. The work area should be well-ventilated.

Specularly reflecting surfaces should be removed from the workplace to reduce the chance of stray reflections. Conservation tools, e.g. scalpels and paint brushes often have shiny surfaces; these should be covered with non-reflecting tape. Care should be taken when wearing jewellery during laser cleaning operations. If the boundaries of the controlled area contain windows then these should be covered using a material, which is opaque to the laser radiation being used (glass transmits most of the wavelengths used in laser cleaning very efficiently). Attention should also be paid to the number of people present in the controlled area. Ideally, only one laser should be used at one time and no other work should be undertaken while the laser is in use. If it is necessary to use more than one laser cleaning system simultaneously, then a controlled area must be created for each laser.

The beam from a class 4 laser can in certain situations set fire to flammable materials. It is, therefore, important to keep all such materials including cleaning solvents away from the beam. It would be prudent to install a suitable fire extinguisher in the work area.

As with other conservation procedures, general health and safety practice should be followed, i.e. no eating, drinking or smoking in the workplace; wash hands and face following laser cleaning work and prior to eating, drinking or smoking. Immediate work areas should be cleaned (using HEPA class filtration industrial vacuum cleaners) following laser cleaning to prevent accumulation of fine particulate matter. The whole of the laser cleaning area should be cleaned at regular intervals.

Laser cleaning for excessive lengths of time can lead to eye strain, in much the same way as prolonged working at a computer screen. Tolerance levels vary from person to person but intense concentration on a small area for an extended period of time can become tiring. Regular breaks (which may simply involve stopping for a few seconds to allow eye muscles time to relax) should be taken.

5.1 Case studies

This section presents case studies to illustrate how the control measures described in chapter 4 can be implemented within a typical conservation environment.

5.1.1 Laser cleaning in a conservation studio

Figures 10-12 show the laser cleaning set-up in the sculpture department of a national museum in the United Kingdom. A controlled area for laser cleaning has been established in a separate room located next to the main sculpture studio. A warning light (connected to the laser cleaning system) and warning signs are clearly visible on the entrance to the room (figure 10). An interlock switch (connected to the back of the laser unit) has been fitted to the door so that access to the room is safe (figure 11). All windows in the room have been blacked out using a material opaque at the wavelength being used. Waste material generated during the cleaning process is removed using the in-built extraction unit by positioning the extraction hood close to the work area. The workplace is well lit. The conservator is wearing protective eyewear and a face mask (figure 12).

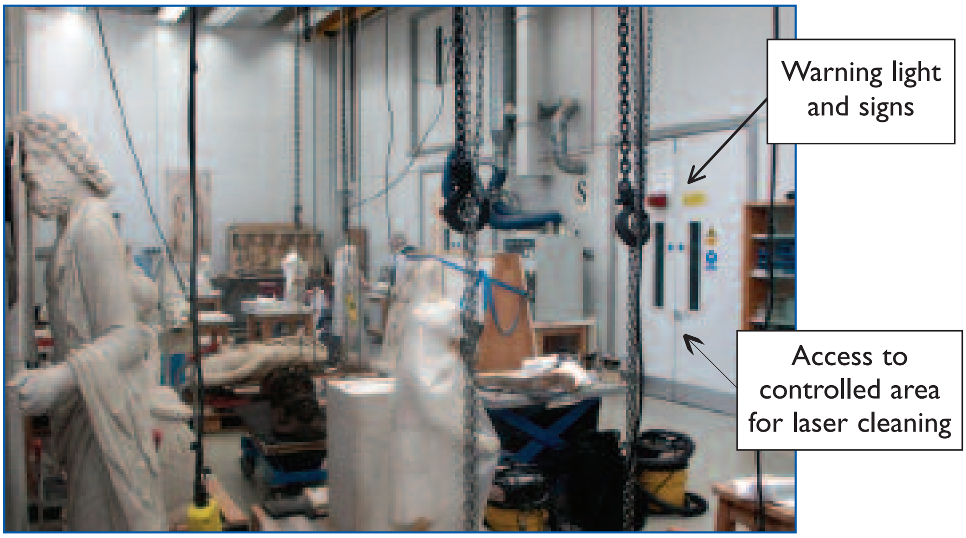


Figure 10 Main sculpture studio with separate room for laser cleaning.

Photo courtesy of National Museums Liverpool.

Figure 11 Controlled area established for laser cleaning.

Photo courtesy of National Museums Liverpool.

Figure 12 Laser cleaning. The conservator is wearing protective eyewear and a face mask and the waste generated during cleaning is removed by a portable extraction unit.
Photo courtesy of National Museums Liverpool.

Figures 13-14 show laser cleaning of a marble statue in an Austrian conservation studio. Once more, a separate enclosed work area has been established to allow laser cleaning to be undertaken safely. Controlled areas can also be created using portable opaque screens. Care must be taken in these situations to ensure that possible reflections from above the workplace (from the ceiling for example) cannot represent a hazard to people working outside the controlled area. Care must also be taken to ensure people cannot accidentally enter the controlled area. Note that the white glazed tiles shown in figures 13-14 are not ideal for the laser work area, a matt surface would remove the possibility of any stray specular reflections.

Figure 13 Laser cleaning of a marble statue. Strong lighting (artificial daylight) is used to illuminate the statue. An in-built extraction unit is positioned close to the cleaning area to remove debris generated during the process.
Photo courtesy of Bundesdenkmalamt Department of Conservation, Arsenal, Vienna.

Figure 14 Detail of laser cleaning of marble statue. Note protective equipment worn by conservator, including gloves.
Photo courtesy of Bundesdenkmalamt Department of Conservation, Arsenal, Vienna.

5.1.2 Laser cleaning in an outdoor environment

Figures 15-17 show the safety features put in place for a test clean, carried out on the balcony of a public building in Liverpool, U.K. The test area was next to a window (figure 15) and access to the balcony area during the test was restricted to those involved in the test. The nominal ocular hazard area extended to street level. Since it was not possible to prevent people from entering this area, a controlled area was established on the balcony by erecting a three-sided protective screen, which was positioned against the wall containing the chosen area (figure 16). The window adjacent to the test area was obscured using opaque material cut to size. Any gaps between the screen and the wall were filled using the same opaque material. In this case a roof for the enclosure was unnecessary as protection from the weather was provided by the building and there was no hazard created by the beam escaping from the controlled area as a result of the absence of a roof (there was no possibility of hazardous specular reflections from the stone surface of the building). When setting up a controlled area on-site, the path of a laser beam escaping from the area (without a roof) should always be considered: specularly reflecting surfaces (e.g. shiny metal pipes) may exist above the work area or windows in the upper floors of a neighbouring building may lie directly in the line of sight. In such cases, people may be inadvertently exposed to hazardous radiation and so a roof should be included (of course, this may also be necessary to provide protection from the weather). Due to the nature of the enclosure, it was not possible to install an interlock to the access point. A warning light was installed and warning signs were fixed to the sides of the enclosure and adjacent to the point of access onto the balcony. All visitors were, therefore, well aware of the test being carried out and the hazardous nature of the laser beam. Inadvertent entry into the controlled area was not possible. Protective eyewear and a face mask were worn by the conservator carrying out the test (figure 17).

Figure 15 Area on the outside of a public building (adjacent to window) chosen for laser cleaning test.
Photo courtesy of National Museums Liverpool.

Figure 16 Controlled area established on balcony using opaque screening.
Photo courtesy of National Museums Liverpool.

Figure 17 Laser cleaning. The conservator is wearing protective eyewear and a face mask and the waste products of the cleaning process are removed from the immediate work area using an industrial vacuum cleaner with HEPA class filtration. The window is blacked out.
Photo courtesy of National Museums Liverpool.

Figure 18 Use of opaque black plastic sheeting to separate laser work area from non-laser work area on scaffolding on the exterior of Chapelle du Saint-Esprit, Rue, France.
Photo courtesy Quélin, France.

Figure 19 Laser cleaning within enclosed area on scaffolding on the exterior of Chapelle du Saint-Esprit, France.
Photo courtesy, Quélin, France.

Figure 20 Use of opaque plastic sheeting to create controlled area for laser cleaning work outdoors.
Photo courtesy of Laserblast, Quantel, France.

Figure 21 Use of tin hoarding on scaffolding to create safe area for laser cleaning on the outside of St. George's Hall, Liverpool.
Photo courtesy National Museums Liverpool.

Figure 22 Laser cleaning within controlled area on scaffolding on St. George's Hall, Liverpool. Note use of opaque sheeting to divide laser work area from non-laser work area. All conservators on scaffolding wore laser safety eyewear whilst laser cleaning was carried out.
Photo courtesy National Museums Liverpool.

Waste products generated during cleaning were removed from the immediate work area using an industrial vacuum cleaner with HEPA class filtration. When working on-site, communication with other contractors is extremely important. All contractors should be made aware of the laser work being carried out and the safety requirements of the laser cleaning contractor should be established at the earliest opportunity to avoid delays and additional costs at a later stage.

Figures 18-22 show laser cleaning on scaffolded sites, where either opaque plastic sheeting or tin hoarding has been used to create a controlled area within which laser cleaning is able to proceed safely. As with working in a studio environment, safe working procedures must be set up prior to work commencing. All conservators who will be working on site must fully understand and comply with the procedures. For site work it is often necessary to have several conservators working at the same time. In such situations it is recommended that the laser work area and non-laser work area are separated by an opaque screen and warning signs are clearly visible. It is important that people cannot accidentally walk into a laser work area.

It is important to stress that the LSO should be responsible for approving outdoor installations before work commences.

Appendix

6.1 Glossary of terms

Absorptance: ratio of the absorbed radiant energy/power to the incident radiant energy/power under the same conditions.
Units: adimensional, but usually presented as percentage (%).

Accessible Emission Limit (AEL): the maximum accessible emission level from a laser product permitted within a particular safety class. AELs depend on laser wavelength and exposure duration. These limits are expressed in terms of energy or power, depending on the *operation mode* of the laser product.

Average power: energy emitted by a laser in one second. Average power of a pulsed laser is equal to (pulse energy) × (*pulse repetition rate*).
Units: Watt (W)

Beam delivery system: the means by which the laser beam is guided from the laser to the surface being treated. In conservation, this is usually via mirrors in an articulated arm or via a flexible optical fibre.

Beam divergence: a measure of how quickly the laser *beam width* increases as distance from the laser increases.
Units: radian (rad) or submultiple, usually milliradian (mrad, $\times 10^{-3}$ rad)

Beam width (diameter): the dimensions of the area of a transverse section of the laser beam. Since laser beams usually have circular or elliptical transverse sections, the beam width is usually referred to as the *beam diameter*. The beam width or diameter is not a constant, but varies along the propagation direction. Beam transversal dimensions must not be confused with dimensions of marks caused by laser radiation on solid surfaces.

Brightness: of a surface is a measure of the amount of light emitted by a surface in the direction of view.

Controlled area (hazard area): an area within which laser hazards associated with a *laser product* are confined. Special controls are implemented within this area to reduce the risk to those working within the area to an acceptably low level. The levels of control will depend largely on the *laser safety classification* of the *laser product* being used.

Electromagnetic (EM) radiation: energy in the form of an electromagnetic wave, composed of oscillating electric and magnetic waves. Visible light is EM radiation with a *wavelength* in the range 400 - 700 nm (0.4 - 0.7 μm).

Energy density (average): (also referred to as fluence or radiant exposure) a measure of the concentration of the *energy* in a laser beam on a surface. Average energy density is given by pulse energy divided by the area of the laser beam on the surface.
Units: Joules per square metre (Jm^{-2}); or submultiples (Jcm^{-2}, $mJcm^{-2}$)

Fluence: see *energy density*.

HEPA class filter: High Efficiency Particulate Air filter.

Infrared (IR) radiation: *electromagnetic radiation* with a *wavelength* within the range 0.7 - 300 μm.

Intrabeam viewing: all the viewing conditions whereby the eye is exposed to direct laser radiation, other than extended source viewing.

Laser: a device producing electromagnetic radiation (EM) with wavelength in the range from 180 nm to 1 mm by controlled stimulated emission. This includes *ultraviolet*, visible and *infrared* light.

Laser explanatory label: rectangular label, in yellow and black, displaying a legend informing: a) main hazards associated with the laser product, b) laser product class, c) laser emission characteristics.

Laser hazard: all hazards associated with the use of a laser or laser product. A hazard is some condition, which has the potential to cause injury.

Laser product: any product incorporating a *laser*.

Laser radiation: the EM radiation produced by a *laser*. Laser radiation is usually pure (single colour or wavelength), highly directional and extremely bright.

Laser safety classification: a classification scheme for lasers and laser systems (numbered from 1 (least hazardous) to 4 (most hazardous)). Every laser product is classified according to the possible hazards posed by the accessible emission of this product.

Laser Protection Adviser (LPA): expert on laser safety, who can be consulted on laser safety issues.

Laser Safety Officer (LSO): person appointed to take responsibility for laser safety on behalf of the employer.

Laser warning label: triangular warning label, in yellow and black, displaying the laser symbol.

Light: see *electromagnetic radiation.*

Maximum Permissible Exposure (MPE): is the level of radiation to which, under normal circumstances, persons may be exposed without suffering adverse effects. MPEs depend on laser wavelength, pulse duration, exposure time and the human tissue at risk. These thresholds are quoted in terms of energy density or power density.

Nominal Ocular Hazard Area (NOHA): defines the area around a laser product, within which an exposure hazard may be present i.e. where the level of laser radiation exceeds the appropriate *maximum permissible exposure* (MPE) for the eye. The NOHA depends on the MPE and the characteristics of the laser beam emitted by the laser product: *beam divergence* and pulse energy.

Nominal Ocular Hazard Distance (NOHD): defines the limit over which an exposure hazard may be present. The NOHD is the distance from the laser product at which the level of radiation equals the appropriate *maximum permissible exposure (MPE)* for the eye. Exposure of the unaided eye to laser radiation at distances from the laser product greater than the NOHD is considered safe. The NOHD depends on the MPE and the characteristics of the laser beam emitted by the laser product: *beam divergence* and pulse energy.

Operation mode: refers to the way in which the *energy* is emitted by the laser, either in continuous mode (CW or 'continuous wave'), as a single pulse or as a stream of pulses, with a definite *pulse repetition rate* (units: Hertz (Hz) or s-1) and *pulse length* (duration of a single pulse, units: second (s) or submultiples of the second, usually microsecond (μs, $\times 10^{-6}$ m) or nanosecond (ns, $\times 10^{-9}$ s)).

Peak power: of a laser pulse is defined as the pulse energy divided by the pulse length.
Units: Watts (W) or Joule per second (Js^{-1}).

Photon: particle of light with associated wavelength, λ, and energy, E. Energy of photon is inversely proportional to its wavelength.

Power density (average): power incident on a surface, divided by the area of incidence.
Units: Watt per square metre (Wm^{-2}); or submultiples (Wcm^{-2}, $mWcm^{-2}$).

Pulse length: duration of a single laser pulse, usually quoted in terms of milliseconds (ms, $\times 10^{-3}$ s), microseconds (μs, $\times 10^{-6}$ s), or nanoseconds (ns, $\times 10^{-9}$ s).

Pulse repetition rate: the number of pulses emitted by a laser in one second.

Pumping source: that part of the laser, which provides energy to the lasing medium to start the lasing process.

Radiant energy and power: energy is the integral of the radiant flux over a given duration; power is the rate of energy emitted per unit time
Units: radiant energy: Joule (J); radiant power: Watt (W)

Reflectance: ratio of the reflected *radiant energy/power* to the incident *radiant energy/power* under the same conditions.
Units: adimensional, but usually presented as percentage (%).

Transmittance: ratio of the transmitted *radiant energy/power* to the incident *radiant energy/power* under the same conditions.
Units: adimensional, but usually presented as percentage (%).

Ultraviolet (UV) radiation: *electromagnetic radiation* with a *wavelength* within the range 30 - 400 nm.

Wavelength: spatial characteristic of electromagnetic radiation, dependent on the material emitting the radiation and determining the colour of the *laser radiation*, if visible.
Units: submultiples of the metre, usually micron (μm, $\times 10^{-6}$ m) or nanometre (nm, $\times 10^{-9}$ m).

6.2 Important laser cleaning systems

6.2.1 Nd:YAG laser cleaning system

The most common laser employed in laser cleaning systems is the Q-switched Nd:YAG laser. This laser uses a cylindrical crystal of yttrium aluminum garnet doped with neodymium ions as the lasing medium. The initial burst of energy is provided by a xenon flashlamp. Laser emission occurs at a wavelength of 1064nm in the near infrared part of the electromagnetic spectrum. A Q-switched Nd:YAG laser will provide laser radiation in pulses of typically 10ns duration. Pulse lengths in the range 30 ns - 50 µs are also available. Other wavelengths can be generated from the 1064nm emission by a non-linear process known as harmonic generation. By passing the emission from a Nd:YAG laser through suitable non-linear crystals, it is possible to generate laser light at one half (532 nm), one third (355 nm) and one quarter (266 nm) the wavelength of the original 1064 nm. A single Nd:YAG laser cleaning system with suitable non-linear crystals can provide a choice of wavelengths ranging from the ultraviolet to the infrared. Laser radiation at 1064nm is delivered using either an articulated arm incorporating specially coated mirrors or an optical fibre. Laser radiation at 532 nm, 355 nm and 266 nm is usually delivered using an articulated arm. Nd:YAG lasers are relatively compact and robust and are, therefore, suited to work in a conservation studio and also on-site.

6.2.2 Excimer laser cleaning system

Excimer lasers use a mixture of two gases as the active medium and provide laser radiation in the ultraviolet part of the spectrum. The KrF excimer laser uses a mixture of krypton and fluorine gases as the active medium, providing emission at a wavelength of 248 nm. Beam delivery is either via an articulated arm or direct from the laser. A KrF excimer laser has been incorporated into a laser cleaning workstation for paintings (see figure 23). Excimer laser cleaning systems tend to be much larger and require more maintenance than Nd:YAG systems and their use is usually restricted to studio work. The gases used in excimer lasers are highly corrosive and require very careful handling during maintenance work.

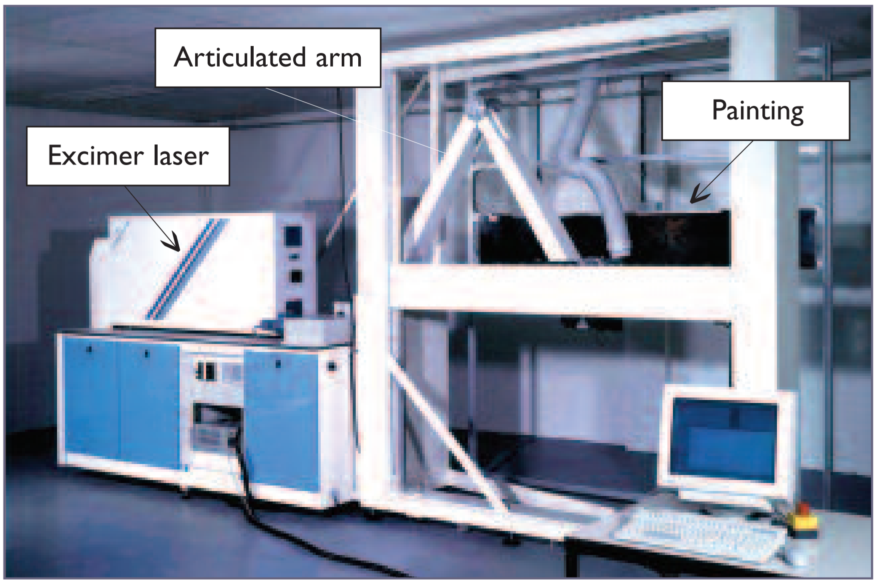


Figure 23 Laser cleaning workstation for paintings incorporating an excimer laser.
Photo courtesy of Art Innovation, www.art-innovation.nl

6.3 Useful information

6.3.1 Laser safety standards

EN 60825-1. Safety of laser products Part 1: Equipment classification, requirements and user's guide.
This is the main European safety standard for laser products.

IEC TR 60825-14: Safety of laser products part 14 (user's guide).
Advice on laser hazards, risk assessments and control measures. Intended to replace user's guidelines in EN 60825-1. Published in the U.K.

EN 207: Personal eye protection – filters and eye protectors against laser radiation (laser eye protectors).
European standard defining performance and testing requirements for laser protective eyewear.

CLC/TR 50448 (European document due to be published).
Guide to levels of competence required in laser safety.

6.3.2 Institutions and organisations

British Standards Institute (BSI): www.bsi-global.com

European Agency for Safety and Health at Work (EASHW): http://agency.osha.eu.int

International Committee on Non-Ionising Radiation Protection (ICNIRP): www.icnirp.de

International Electrotechnical Commission (IEC): www.iec.ch

International Standardization Organization (ISO): www.iso.ch

Health Protection Agency: www.hpa.org

6.3.3 Laser safety publications

Laser Safety, by Roy Henderson and Karl Schulmeister, Institute of Physics Publishing, Bristol, January 2004, ISBN 0750308591.

Handbook of Industrial Laser Safety (CD), by Karl Schulmeister, Thomas Puester, Mike Green and Roy Henderson, Austrian Research Center Seibersdorf: http://info.tuwien.ac.at/islt/safety

Industrial Laser Safety, edited by Mike Green (Prolaser Consultants), Summary of Eureka project EU 643 'Safety in the Industrial Applications of Lasers' (1992-1996).

6.3.4 Laser safety on the web

A Brief Guide to Laser Safety: http://www.bioptica.co.uk/lasersafety.htm
General rules and precautions with references for further reading.

Elements of Laser Safety: http://gary.myers.net/elements.htm
Mainly discusses how the human body, especially the eye, can be affected by various freqencies of laser radiation.

Handbook of Industrial Laser Safety: http://info.tuwien.ac.at/islt/safety
Information on laser radiation, laser hazards, gas and fume emission, risk assessment, training and education, safety standards.

Laser Accidents: http://www.adm.uwaterloo.ca/infohs/lasermanual/documents/section11.html
Summaries of reported laser accidents in the United States and their causes from 1964 to 1992.
They indicate that the majority of injuries involve the eye and occur during alignment procedures, or because the protective eyewear was either inappropriate or not used.

Laser Hazards: http://www.adm.uwaterloo.ca/infohs/lasermanual/documents/section6.html
Eye and skin hazards from laser light.
Laser Institute of America: www.laserinstitute.org/safety_bulletin/lsib/

Lasers in Health Care: http://www.ccohs.com/oshanswers/phys_agents/lasers.html
Questions and answers on the use of lasers in health care.

Non-Beam Laser Hazards: http://www.adm.uwaterloo.ca/infohs/lasermanual/documents/section7.html
Various electrical, radiation, fire, explosion and chemical hazards.

Rockwell Laser Industries: http://www.rli.com/
Laser safety consulting, training and a full line of safety products including eyewear, barriers, signs, hazard analysis software and instructional materials. Site includes much safety related information.

6.3.5 Laser safety consultancy and training

Association of Industrial Laser Users www.ailu.org.uk

Austrian Research Centre Seibersdorf www.healthphysics.at/laser

Bioptica www.bioptica.co.uk

Irepa Laser www.irepalaser.fr

Prolaser Consultants www.prolaser.co.uk

6.3.6 Laser safety equipment suppliers

Lasermet Ltd www.lasermet.com

Laser Physics U.K. Ltd. www.laserphysicsuk.com

6.3.7 Laser cleaning

EU COST Action G7: 'Artwork Conservation by Laser' http://alpha1.infim.ro/cost/

6.4 Summary of safe working practice

This is intended to provide a brief summary of good safe working practice for conservators undertaking laser cleaning activities with a class 4 laser cleaning system, emitting visible or near infrared radiation. This summary must not be used without prior reading and understanding of the detailed information provided by this booklet.

6.4.1 General

- Written procedures based on the findings of a risk assessment should be in place and followed.
- Potential users of laser systems must receive appropriate training before being allowed to start laser cleaning work.
- Servicing and maintenance of laser cleaning systems must only be carried out by people who have received the appropriate training and have the relevant expertise.
- Store keys to laser cleaning systems away from the systems.
- Appoint Laser Safety Officer.
- Regularly check safety controls and ensure compliance among staff.
- Take regular breaks during laser cleaning activities to avoid eye/muscle strain.
- Only one person should be working within the controlled area at any time (anyone else should only be observing).
- Consult with Laser Protection Adviser (possibly expert from outside organisation) if extra advice required.

6.4.2 Laser environment

- Laser cleaning should be carried out in a controlled area within which the laser beam is confined.
- If there is no roof to the controlled area, ensure that the laser beam cannot pose a hazard to people within the nominal ocular hazard area.
- Ensure windows covered by material opaque to the wavelength(s) being used.
- Ensure laser warning signs and warning light are clearly visible.
- Ensure access to controlled area is restricted; use interlocks if possible. Inadvertent entry into the controlled area should not be possible.
- The work area should be well-illuminated.
- Remove shiny objects, e.g. scalpels, from the vicinity of the object being cleaned.
- Only one laser cleaning system should be used within a single controlled area.
- Do not put water containers on top of the laser cleaning system.
- Use localised extraction to remove debris at source. Ensure equipment used correctly and filters changed when necessary.
- Ensure all power cables, leads etc. do not present tripping hazard.
- Clean the work area regularly to avoid accumulation of debris over time.

6.4.3 Personal protection

- Wear appropriate laser safety eyewear.
- Ensure eyewear fits correctly.
- Clean eyewear only with appropriate fluid and soft tissue/cloth.
- Store eyewear carefully to avoid damage.
- If changing wavelength, ensure correct eyewear in place before starting work.
- Replace eyewear if damaged.
- Ensure all people inside controlled area are wearing safety eyewear at all times while laser is operating.
- Avoid exposure of skin to laser radiation and fine particulates emitted during cleaning.
- Wear an appropriate face mask during cleaning.

6.5 Laser safety eyewear checklist

Laser safety eyewear is usually supplied through the manufacturer of the laser cleaning system or a specialist laser eyewear supplier. The eyewear must be CE marked and will provide a level of protection given by the L number at the wavelength being used. Safety eyewear with protection of L6 for example will attenuate the laser beam by at least 99.9999%, i.e. a maximum of 0.0001% of the beam striking the filters will pass through. The level of protection required by the user to reduce the beam to a safe level will depend on its wavelength, pulse length, maximum pulse energy, maximum repetition rate and divergence from the handpiece. These pieces of information should be written in the instruction booklet of the laser cleaning system and will be requested by a supplier when calculating a suitable level of protection.

It is important to note that it is usually necessary to change safety eyewear when changing the wavelength at which cleaning is being undertaken. It may also be necessary to change eyewear when moving between the same type of laser cleaning system, e.g. Nd:YAG, if the specifications differ significantly. It is, therefore, necessary to know the L number required for each laser cleaning system in the studio or on-site.

Laser safety eyewear will have a label showing the level of protection at different wavelengths and pulse lengths.

Wavelength	Continuous beam (D) long pulse (I) short pulse (R)
950-1047	**D** L5 **+** **IR** L6
>1047-1400	**D** L5 **+** **IR** L7
>1400-1580	**D** L2 **+** **I** L3
2090-2100	**D** L2 **+** **I** L3
2900-2940	**D** L2 **+** **I** L3
10600	**D** L2 **+** **I** L3

Table 5 Typical label on laser safety eyewear.

For a laser operating at 1064 nm, emitting short pulses (R) protection would be L7.

For a continuous laser (D), emitting at 10600 nm, protection would be L2.

Information required to calculate level of protection required for eyewear:

Wavelength: .... nm

Pulse length: .... s

Maximum pulse energy: .... mJ

Maximum pulse repetition rate: .... Hz

Beam divergence from handpiece: .... mrad

COST – the acronym for European **CO**operation in the field of **S**cientific and **T**echnical Research – is the oldest and widest European intergovernmental network for cooperation in research. Established by the Ministerial Conference in November 1971, COST is presently used by the scientific communities of 35 European countries to cooperate in common research projects supported by national funds. The funds provided by COST – less than 1% of the total value of the projects – support the COST cooperation networks (COST Actions) through which, with only around E20 million per year, more than 30.000 European scientists are involved in research having a total value which exceeds E2 billion per year. This is the financial worth of the European added value which COST achieves. A "bottom up approach" (the initiative of launching a COST Action comes from the European scientists themselves), "à la carte participation" (only countries interested in the Action participate), "equality of access" (participation is open also to the scientific communities of countries not belonging to the European Union) and "flexible structure" (easy implementation and light management of the research initiatives) are the main characteristics of COST. As precursor of advanced multidisciplinary research COST has a very important role for the realisation of the European Research Area (ERA) anticipating and complementing the activities of the Framework Programmes, constituting a "bridge" towards the scientific communities of emerging countries, increasing the mobility of researchers across Europe and fostering the establishment of "Networks of Excellence" in many key scientific domains such as: Physics, Chemistry, Telecommunications and Information Science, Nanotechnologies, Meteorology, Environment, Medicine and Health, Forests, Agriculture and Social Sciences. It covers basic and more applied research and also addresses issues of pre-normative nature or of societal importance.

Laser-based techniques offer many unique possibilities for the examination and conservation of artworks. The laser is a modern, highly controllable and versatile tool. COST Action G7 'Artwork Conservation by Laser' has been set up to address challenges in three main areas: (i) **Laser systems for investigation and diagnosis;** (ii) **Laser systems for real-time monitoring of environmental pollution;** (iii) **Laser Systems for cleaning applications.**

COST G7 home page:
http://alpha1.infim.ro/cost/pagini/home.html

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