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MINISTRY OF DEFENCE

MILITARY LASER SAFETY

BY COMMAND OF THE DEFENCE COUNCIL

MINISTRY OF DEFENCE

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Amendment no.	Reference	Date of insertion	Initials
1	Removal of activity milestones for laser safety clearance and staff targets / Cardinal points specifications / staff requirements from Chapter 9.	02/11/05	TJR

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PREFACE

This Joint Services Publication (JSP) provides mandatory instructions on laser safety for the UK Armed Services and Ministry of Defence (MOD) Establishments in the conduct of research and development, trials, procurement, training and maintenance involving the use of lasers within the United Kingdom and overseas. Civilian contractors and foreign agencies associated with any of these activities, and private venture usage on MOD property, also come within the jurisdiction of this JSP. Within this JSP, the term *Service* applies to all these agencies. These instructions are applicable for operations; where, however, the ultimate responsibility for safety rests with the Commander.

JSP 390 is primarily concerned with the laser hazard and its control, but can also be applied to non-laser light sources in the absence of other suitable guidance. It extends the treatment of laser hazard evaluation beyond that which appears in other codes, for the benefit of the Armed Services. There are sections covering laser principles and reviewing the structure and response of the eye, which are intended to educate; but these are not necessary for an appreciation of the evaluation of hazard. The formulae used for laser hazard assessment in Annex 3A are intended to allow a mathematically-competent person to carry out the evaluation.

For the purposes of brevity, JSP 390 does not give a prescription for laser classification assignment, therefore reference should be made to the British Standard for this procedure. Wherever the term *British Standard* is used in this JSP, the current standard should be inferred: at the time of printing this is **BS EN60825-1:1994 + Amendments 1, 2 & 3:2001**

The Bibliography lists current laser safety standards and also shows their inter-relationship. JSP 390 is the UK implementation of NATO Standardization Agreement (STANAG) 3606.

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Acknowledgements

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CHAPTER 1

INTRODUCTION TO LASERS

GENERAL

1. The word LASER is an acronym for Light Amplification by Stimulated Emission of Radiation, and is usually associated with emission in the near-ultraviolet, visible and infrared regions of the electromagnetic spectrum (see Fig. 1-1). A laser produces a beam of highly-monochromatic electromagnetic energy of high intensity, which is concentrated into a narrow beam of very small angular divergence. The brightness of a laser source can exceed that of all other man-made light sources and all known natural light sources, including the sun as seen from the earth. Annex 1A includes a chronology of important events in the development of the laser.

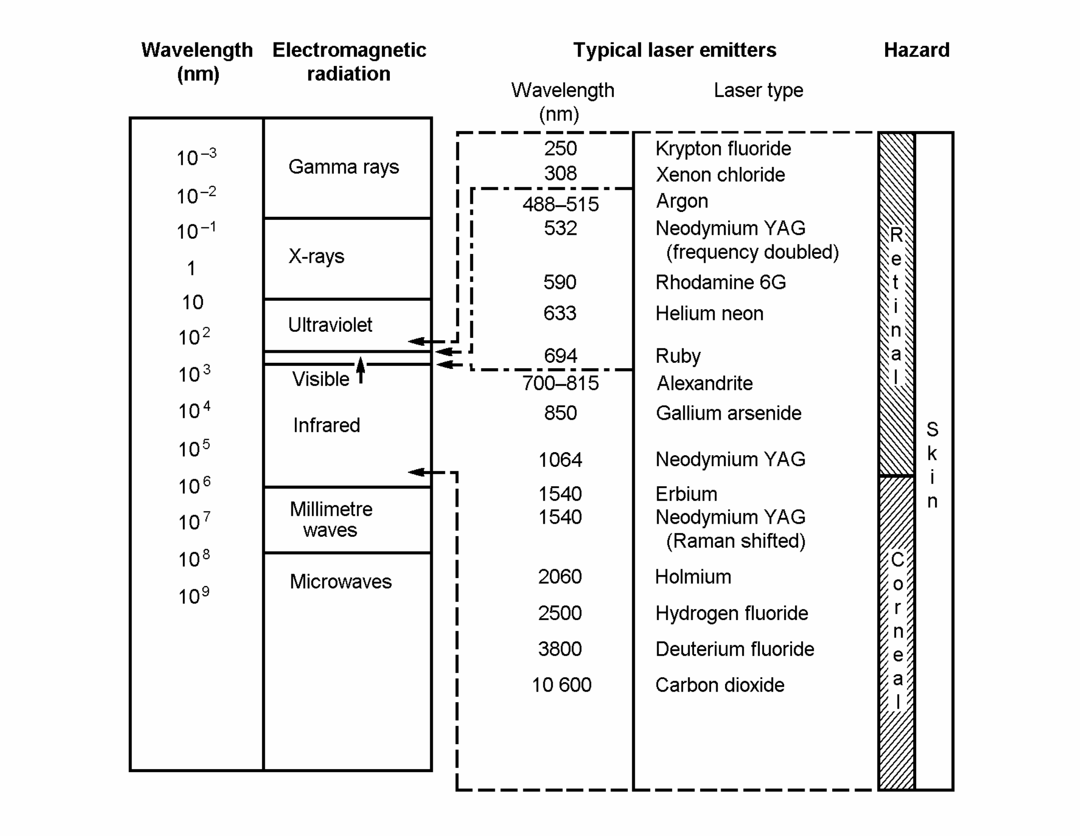

Fig. 1-1 Electromagnetic Spectrum

What is a laser?

2. Laser light is distinguished from ordinary light in that it is coherent; that is to say, composed of wave trains vibrating in phase with each other. This feature results in a very intense, highly-monochromatic and highly-directional beam of radiation which may be dangerous to human tissue and in particular to the eyes. The difference between ordinary light and laser light is illustrated in Fig. 1-2.

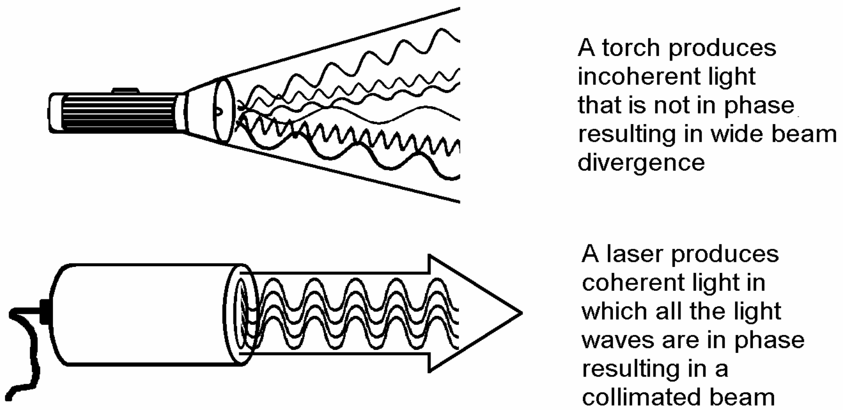

Fig. 1-2 Ordinary light and laser light

How does a laser work?

3. The basic elements of a laser are a working medium having suitable optical characteristics, a source of energy to pump the medium, and an optical resonator to amplify the signal.

4. Quantum theory shows that matter can exist in only certain allowed energy levels or states. Source energy is converted into optical energy through excitation of the atomic or molecular species in the working medium. All atoms and molecules contain orbiting electrons which are distributed at discrete distances from their centre (nucleus). An atom/molecule is then said to be excited when one or more of these electrons has been raised, by absorption of the pumping energy, from its normal ‘ground-state’ energy level to a higher energy level. Subsequently, the electrons may return to the ground state or to some intermediate state with the emission of fluorescence radiation whose frequency and wavelength are related to the energy difference between the two states.

5. There are two processes by which the atom becomes de-excited, producing fluorescence radiation, and these are illustrated schematically in Fig. 1-3. The first process, which is the mechanism of spectral emission from all natural sources, is called *spontaneous emission* and results from spontaneous de-excitation of the atom. As this process occurs randomly there is no phase relationship between the individual emissions, thus no amplification of the light output, and the radiation is said to be incoherent (as in the normal fluorescent tube in most offices).

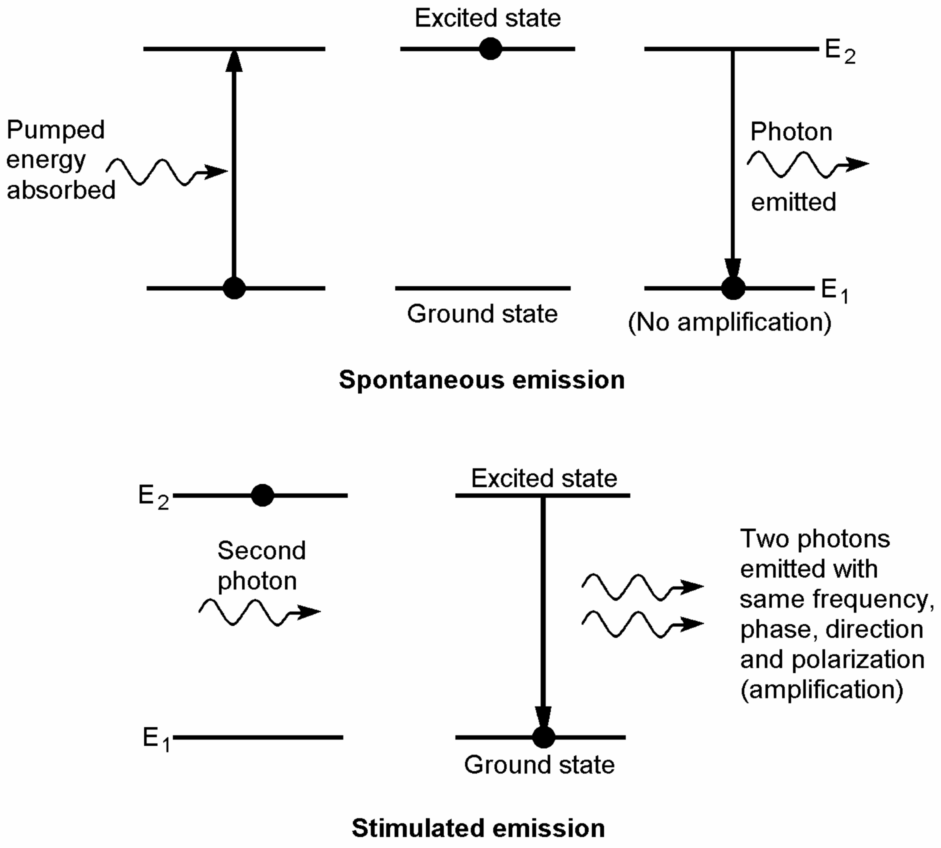

Fig. 1-3 Process of de-excitation

6. The second process is called *stimulated emission* and is the mechanism for generating laser radiation. This occurs when the atom in its excited state is further excited by a *photon* of energy exactly equal to the difference between the ground and the excited level. The incident photon triggers the emission of another identical photon having the same energy, wavelength, phase, state of vibration (polarization) and travelling in exactly the same direction. The two photons are said to be *coherent* with one another both in time and space. They are temporally coherent, resulting in a high degree of monochromaticity, and spatially coherent, resulting in a high degree of directionality. Furthermore, they interfere with one another to produce a single wave of twice the amplitude. This process of amplification is magnified many hundreds of millions of times by all the photons interacting throughout the working medium, and produces a very intense output laser beam (which can be injurious to eye and skin).

7. In order to sustain the process of stimulated emission, the population of the higher excited electronic states must be greater than that of the ground state. This is the inverse of the natural state of matter and is referred to as *population inversion.* To achieve a state of population inversion external energy must be fed into the lasing medium by a process called *pumping.* This can be carried out by optical, electrical, chemical, nuclear, thermal or electromagnetic methods.

Pumping is normally achieved:

a. For solid-state or semiconductor lasers (e.g. neodymium yttrium aluminium garnet, Nd:YAG) by xenon flash lamp.

b. For gas-discharge lasers (e.g. carbon dioxide, CO_2) by direct current (DC), radio frequency (RF) pulsed arc-discharges or electron beams.

c. For semiconductor lasers by direct current injection

d. For chemical lasers by chemical exothermic reactions

e. For gas-dynamic lasers by thermal pumping.

f. For liquid dye lasers by flash lamp or laser.

8. The de-excitation process for a practical laser is more complicated than the two-level scheme of Fig. 1-3. Three-level and four-level schemes are shown in Fig. 1-4. In each case, the laser emission is from an intermediate state either down to the ground state (3-level) or to another intermediate state (4-level). Because the lower intermediate state in the 4-level system can be cleared by fast decay, it maintains the condition of population inversion better than in the 3-level system and therefore leads to higher efficiency. The Nd:YAG laser is a 4-level system, giving it a higher efficiency than the 3-level ruby laser which it has replaced in rangefinder operations.

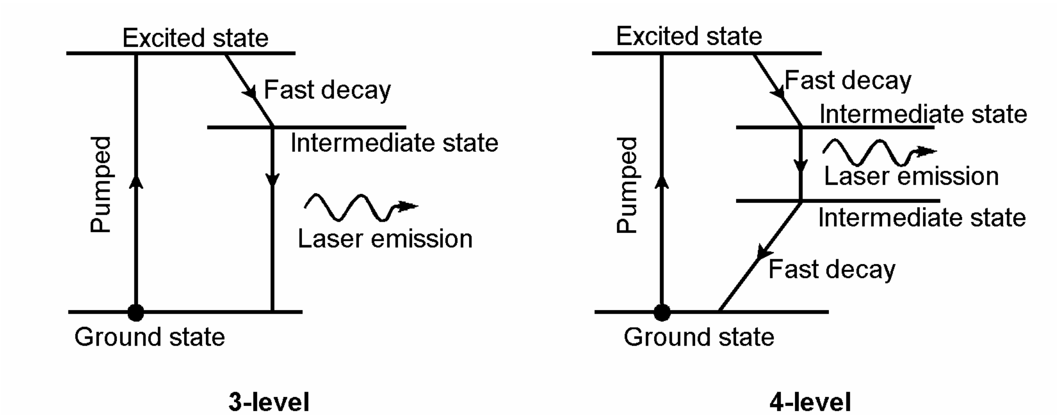

Fig. 1-4 De-excitation transitions for practical lasers

9. Many electronic levels are involved in practical lasers and several laser outputs of different frequencies can be produced. Normally, all frequencies but one are quenched by using interference coatings on the minors which selectively reflect the frequency required for the application.

10. To produce a significant output the laser medium is normally contained in a cavity resonator

(shown schematically in Fig. 1-5). The action of the cavity is to increase the optical path by use of two mirrors which reflect the laser light backwards and forwards within the cavity, producing resonant amplification by stimulated emission. The effect is to produce a single-frequency wave that grows in amplitude as it resonates within the cavity. One of the mirrors is semitransparent to allow a portion of the beam to escape through it, thus creating the output of the laser. Only waves which are moving in a direction very nearly parallel to the axis of the cavity are present in the output and this gives the laser beam its high degree of directionality.

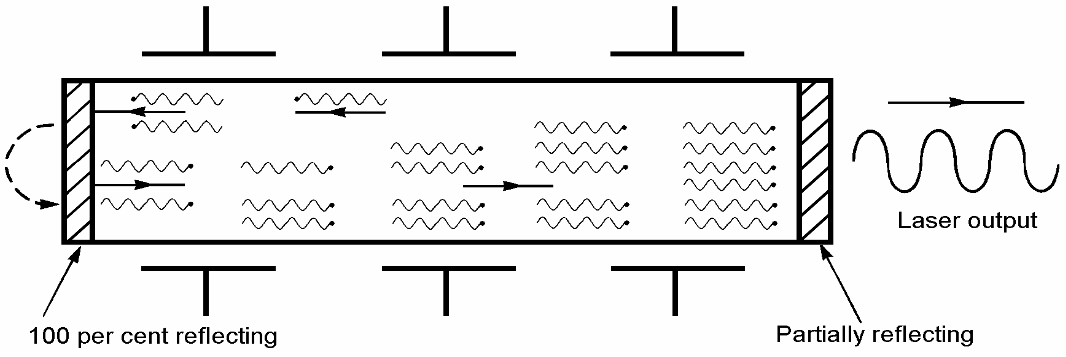

Fig.1-5 Concept of a cavity resonator

11. Because spontaneous emission always dominates stimulated emission, a laser has a relatively very low efficiency. The energy lost in the system appears as incoherent light and heat, the latter requiring cooling installations in high average power lasers, adding to complexity and cost.

12. Lasers can provide either a continuous output beam (continuous wave, CW), a single pulse (SP) or a series of pulses (repetitively-pulsed, REP). Units of watts are used to describe the average power of a CW or REP beam and joules are used when referring to the energy of a single pulse.

OPERATIONAL LASERS

13. The lasers most likely to be encountered in a Service environment are briefly described in the following paragraphs, and are grouped according to their working medium. (Annex 1A includes a chronology of military lasers entering service.)

Solid-state lasers

14. *The ruby laser.*

a. This laser is based on laser action in triply-charged chromium ions held in an aluminium oxide lattice which acts as a host material. It was the first successful solid-state laser, and was originally arranged as shown in Fig. 1-6(a). In a modern ruby laser, a cylindrical rod of this material is arranged at one of the foci of an elliptical cylinder of highly-reflecting walls and a xenon white flash tube is arranged at the other focus, as shown in Fig. 1-6(b). Energy stored in a bank of capacitors is discharged into the xenon flash lamp, which provides white light pumping into the ruby rod to trigger laser action. The laser beam is emitted from one end of the ruby rod along the direction of the axis. The wavelength of the pulse of light emitted is 694 nm, which lies in the red portion of the visible spectrum.

b. Ruby lasers are inefficient and convert only about 0.1 per cent of the energy from the xenon flash into laser light. In consequence, they are designed so that the remaining energy can be dissipated as heat from the system. A limitation must therefore be imposed on the number of pulses that can be obtained in a given time from a ruby laser. If this limitation is not observed, excess heating will occur and the crystal may shatter. A ruby laser rangefinder was used in the Chieftain Main Battle Tank.

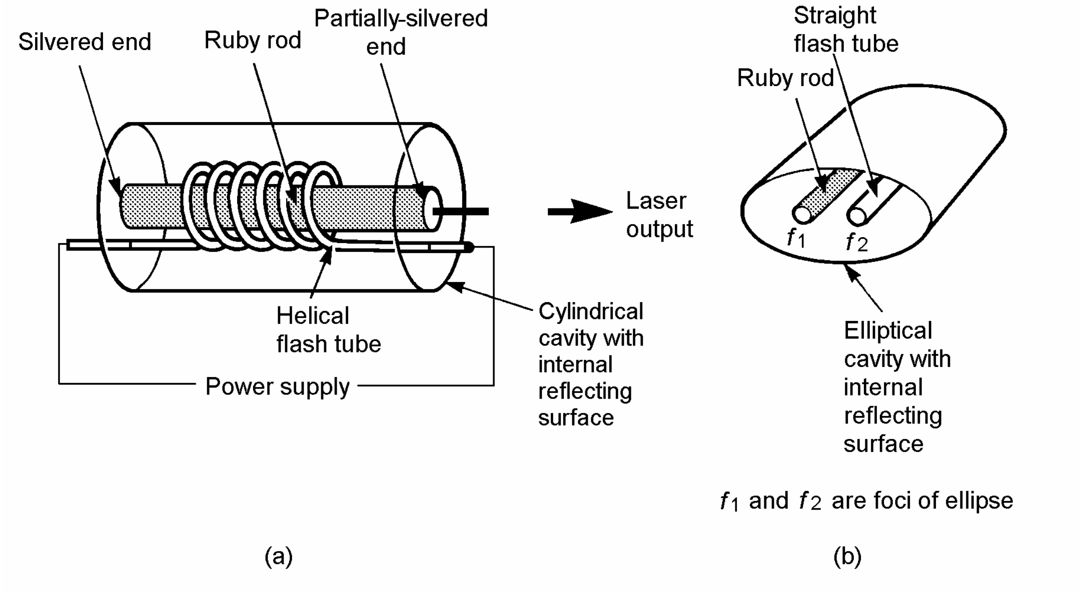

Fig. 1-6 Cylindrical and elliptical cavity ruby laser

15. *The neodymium YAG laser*. This is also a solid-state device using an elliptical cavity based on laser action in triply-charged neodymium (Nd) ions held in a host lattice of yttrium aluminium garnet (YAG). It is denoted by the symbol Nd:YAG. Its principle of operation is the same as that of

the ruby laser, but the operating wavelength is in the near-infrared at 1064 nm. The neodymium YAG laser has an efficiency of 1 to 2 per cent and, because the YAG host material has relatively good thermal properties in addition to its good optical transmission, it is capable of being operated at higher pulse repetition frequencies and average power levels. Typically, these lasers can operate in SP or in REP mode at up to 20 pulses per second. It is used for target rangefinding and designation in land, sea and air operations.

16. *The Raman-shifted Nd:YAG laser.* The process of Raman shifting (see paragraph 41) is used to change the wavelength of the Nd:YAG laser from 1064 nm to 1540 nm. The conversion efficiency is typically 30 per cent and it has the effect of changing the output to a less hazardous wavelength, which has significantly reduced retinal hazard.

17. *The diode-pumped Nd:YAG laser.* In this laser, the host Nd:YAG laser is pumped by a very narrow line-width diode laser injected into its cavity during the time the Q-switch (see paragraph 34) opens.

18. *The holmium laser.* This is similar to the neodymium YAG solid-state laser, with laser action taking place in ions of holmium in yttrium aluminium garnet (Ho:YAG) or, for greater efficiency, in yttrium lithium fluoride (Ho:YLF). It operates at a wavelength of 2060 nm, which lies outside the retinal hazard bandwidth and therefore can be safer than the neodymium YAG laser.

19. *The erbium YLF (Er:YLF) laser.* This is another solid-state laser which operates at 1540 nm and has similar eye hazards to Raman-shifted Nd:YAG.

20. *The alexandrite laser.* The host material of this laser is alexandrite chrysoberyl Al_2BeO_4, and the laser active dopant is the triply-charged chromium ion Cr^{3+}. Broad emission output bands give it the capability of being tuned over the range 700 to 815 nm.

Semiconductor lasers

21. *The gallium arsenide laser*. This semiconductor laser, which is also known as an *injection laser* or *diode laser,* is based on the energy emitted when electrons and holes in a p-n junction diode, made from doped gallium arsenide (GaAs), recombine across the junction. The design of the p-n junction is such that it acts as its own resonating cavity, no external mirrors being needed. It is illustrated in Fig. 1-7. The pumping is by current injection, and CW power of several watts at a wavelength of 850 nm (with about 10 per cent efficiency) is obtainable. It is used, for example, in light emitting diodes (LEDs) for communication lasers, for infrared laser illuminators and effects simulators used for tactical exercises.

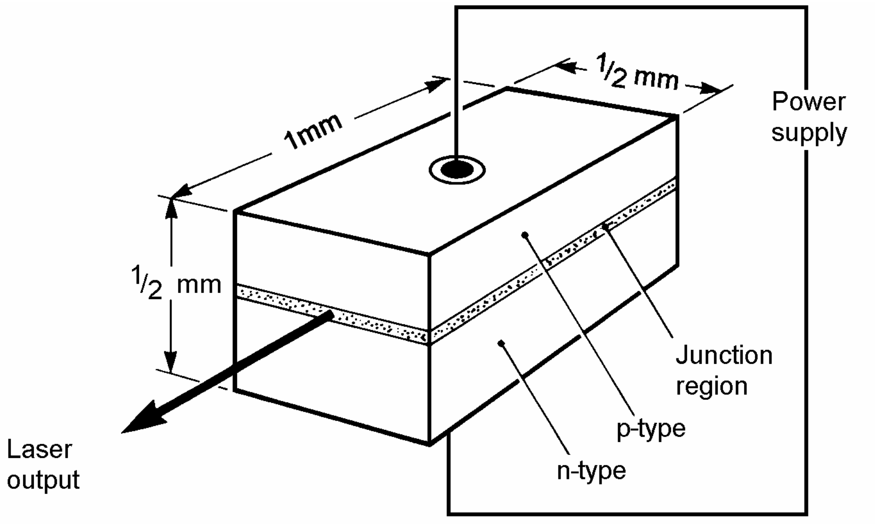

Fig. 1-7 A semiconductor laser

Gas lasers

22. *The helium-neon (HeNe) laser.* This is a gas laser in which the laser action takes place in neon atoms with the pumping being achieved by a gas discharge in helium and collisional transfer of energy to the neon. Its operating wavelength lies mainly in the infrared region but it also has an output at 633 nm in the red part of the visible spectrum. The most common construction using external mirrors is shown in Fig. 1-8. It is a CW laser with a power output in the order of milliwatts and an efficiency of a few per cent. Its main applications are as an alignment tool for other lasers, surveying and holography (three-dimensional imagery).

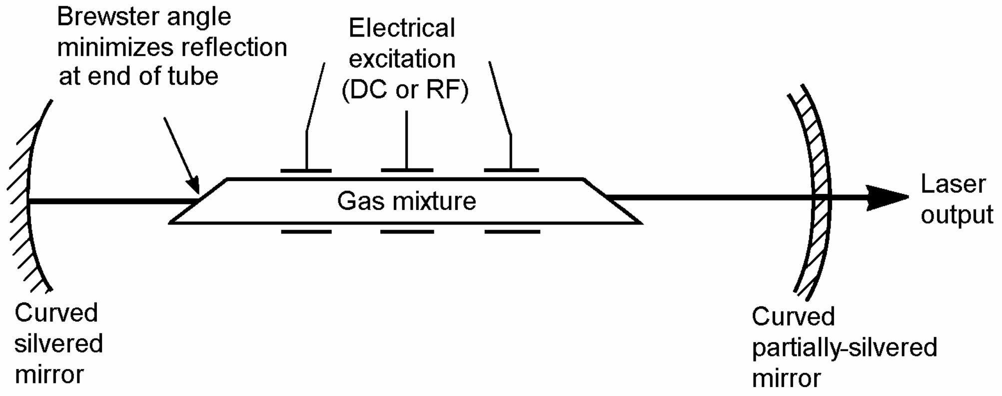

Fig. 1-8 A gas laser

23. *The argon laser.* This gas laser operates using energy levels in argon ions and can be tuned to provide outputs of a few watts CW in the blue at 488 nm or the green at 515 nm. Its main applications are in laser machining and holography.

24. *The carbon dioxide (CO_2) laser.* In this gas laser the electron transitions take place within molecular energy levels in carbon dioxide and the important output wavelength is 10,600 nm, This lies in the middle of the far-infrared atmospheric window. Because of its very long wavelength, it has better penetration of mist and smoke than visible and near-infrared lasers. It is capable of operating at several kilowatts average power for industrial use. Its efficiency is of the order of 10 to 20 per cent and its main applications are in laser machining, surgery, laser radar (ladar), remote sensing and rangefinding.

25. *The gas-flow CO_2 laser.* In the gas-flow carbon dioxide laser a constant supply of gas is pumped into the laser tube and lasing is initiated by an electrical discharge along the axis of the tube (longitudinal discharge). The power output for this type of laser is typically 60 W increasing linearly with tube length, giving a limit of a few kilowatts. Output power can be improved by increasing the flow of the gas through the tube and/or increasing the length of the tube.

26. *The Transversely Excited Atmospheric (TEA) CO_2 laser.* Another possible method of increasing the laser output is to increase the pressure of the gas in the tube. The problem with this is that the voltage required to initiate the discharge becomes very large as the pressure increases: this makes a longitudinal discharge impractical. Also, for sufficiently-high pressures, discharge instabilities mean that CW operation is precluded. The problem of the discharge voltage is overcome by switching to a transverse geometry. Hence, high-power carbon dioxide lasers operate in a pulsed mode, pumped using a transverse discharge.

27. *The chemical laser.* This type of laser works on the basis of combustion of gases to produce excited molecular vibration states which decay with emission of laser radiation. Examples are hydrogen fluoride (HF), working at 2500 nm, and deuterium fluoride (DF), which works at 3800 nm. Very small versions are available for research use.

28. *The excimer laser.* This laser combines rare gas and halogen atoms in excited states to form excimers. When the molecule is de-excited by laser action, it breaks up on reaching the ground state, thereby ensuring good population inversion and relatively-high operational efficiency. Pumping is achieved by electrical discharge or by electron beam excitation, and emission is by very short pulses. Examples are krypton fluoride (KrF) operating at 248 nm and xenon chloride (XeCl) working at 308 nm. Large energy devices are being explored for tactical applications, but small lightweight versions are marketed and have applications in surveillance.

Liquid lasers

29. *The liquid dye laser.* There are several fluorescent dyes that exhibit laser action in solution, the chief one being rhodamine 6G, working at 590 nm. These dye lasers operate in CW, SP and REP modes and are tunable over a wide spectral range from the visible to the near-infrared.

Although liquid dye lasers are mainly used in research laboratories, they are under development for coded optical communication system

High energy lasers

30. The technology exists to create very high average power lasers which could be used to damage targets remotely. In order to achieve maximum damage effectiveness, the output laser beam from these systems is convergent and consequently the hazard distances are enormous. The lasers described below are not in general Service use.

31. *The gas-dynamic CO_2 laser.* In this type of carbon dioxide laser, the population inversion is created by thermodynamic means rather than by an electrical discharge. A nitrogen/CO_2 mixture is heated and compressed, then allowed to expand rapidly through a nozzle into a low-pressure chamber. The energy is stored in the vibrational modes of the nitrogen molecules and is then transferred to the CO_2 molecules by a collision process. It is possible for this type of laser to produce output powers of several hundred kilowatts.

32. *The gas-dynamic chemical laser.* This is a larger version of the chemical laser (see paragraph 27) but works on the gas-dynamic technology (see paragraph 31), achieving megawatts of output power.

33. Multi-megawatt lasers have been researched and partly developed for strategic defence. The *free electron laser* relies upon the interaction of a very high energy electron beam with an alternately-poled magnetic field which is placed within the cavity resonator, producing coherent radiation by electric dipole oscillation. It can be tuned over a very wide range of frequencies (wavelengths). The *X-ray laser* has such extremely low conversion efficiency that it would have to be pumped by a nuclear weapon explosion and is still in the concept stage.

ASSOCIATED TECHNIQUES

Q-switching

34. The technique of *Q-switching* is employed with solid-state lasers to achieve very short intense pulses of nearly-monochromatic laser radiation for laser ranging and target designation applications.

35. Q-switching involves changing the ‘quality’ of the cavity. Initially, the cavity mirrors are removed and pumping allows the population inversion to build up to a very high value of single-mode oscillation without the feedback which would have built up higher-order mode oscillations. After the population inversion has achieved the highest possible value, the mirrors are switched back into the system, suddenly increasing the Q-factor and feedback, allowing the whole of the

stored energy to be emitted in one short, very intense pulse, essentially of a single mode (TEM_{00}) oscillation (see paragraph 47).

36. Q-switching can be done in several ways. In one method, an octagonal mirror, or porro-prism, is rotated at high speed, e.g. 30,000 rpm, and only when this is aligned with the stationary mirror is the energy released as laser output (Fig.1-9). This type of device produces pulses of length 50 ns and ranging accuracy of approximately 1 m, but the switching speed is relatively slow compared with electronic techniques.

37. A faster switching method employs an electro-optically active crystal which is placed within the laser cavity as shown in Fig. 1-10. This crystal is opaque to the laser light except at the instant when an electric potential is applied. This is triggered by the flash tube which initiates the discharge, thus allowing the population inversion to build up in a controlled way before laser action is initiated. With this technique, output pulses of length 10 ns can be produced, increasing ranging accuracy over the mechanical method.

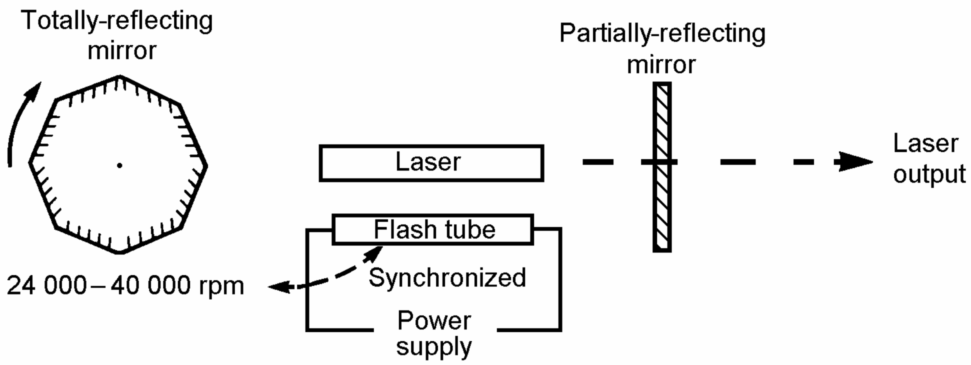

Fig. 1-9 Q-switching using an octagonal mirror

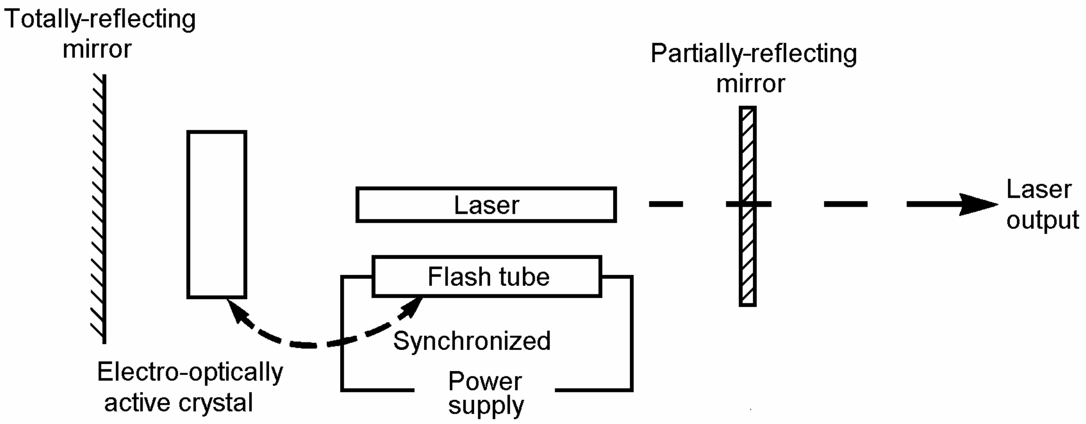

Fig 1-10 Q-switching using an electro-optic switch

38. Another method of Q-switching is through the use of saturable dyes. In this method, the laser energy is absorbed by the dye in the Q-switch, until the dye is saturated and unable to absorb any more energy; the dye then becomes transparent, allowing the laser energy to be emitted.

39. A more advanced method is to use *mode-locking.* A mode-locked laser works on the basis of interference of the phases of the different modes of oscillation in the laser beam to produce a beat effect. The result on the laser output is to produce regularly-spaced pulsations over a period up to several nanoseconds, containing individual pulses of length 0.1 ns. This pulse length is some one hundred times shorter than that of the electro-optic Q-switch creating much higher peak powers and causing much more intense ocular effects.

Frequency doubling

40. Frequency doubling involves the use of electro-optical material to absorb an incident laser beam and to cause two photons at one wavelength to produce one photon at half the wavelength (i.e. double the frequency). In this way, an Nd:YAG laser output at 1064 nm in the near-infrared can be turned into one at 532 nm in the green part of the visible spectrum.

Raman shifting

41. Raman shifting is a process by which electromagnetic radiation is scattered by atoms and which causes a change in wavelength that is dependent upon the nature of the scattering medium. Hence, a Raman-shifted laser beam is produced by directing the output of a laser source into a Raman-active cell. The cell acts to convert the incident radiation to a longer wavelength (typically, the 1064 nm Nd:YAG laser is Raman-shifted to 1540 nm).

Nonlinear optics

42. This field is concerned with the interaction of optical radiation with materials (either solid, liquid or gas) in which a nonlinear optical response occurs, resulting in an intensity-dependent variation characteristics. Although these nonlinear effects were known before the advent of the laser, it is the very high intensities of this device which have substantially expanded the range of materials and effects, allowing a considerable increase in scope and application, some of which are of interest to military technology.

43. Of particular relevance to laser safety are the developments in wavelength shifting to produce a laser with reduced retinal injury and in optical switching for a laser goggle which could protect against a tunable laser.

44. Another example is the phenomenon of *optical phase conjugation.* This has use in adaptive optics systems to correct automatically for wavefront aberration, thus achieving a better quality laser beam output or improving laser beam propagation through the atmosphere.

LASER BEAM PROFILE

45. The laser beam characteristics feature prominently in hazard evaluation. Care should therefore be taken over the parameters that should be used when defining beam divergence, beam diameter and the type of output beam energy distribution profile. It must be appreciated that no definition of beam divergence has any significance unless it is related to a parallel definition of the beam energy distribution.

46. The modes of oscillation within the resonant cavity are an integral part of laser operation. Each mode contributes to the shape (quality) of the output beam profile, and a mixture of modes produces an irregular shape. Only the lowest-order mode, or ‘uniphase’ mode, produces perfect coherence and a pure *gaussian* beam profile; and such a mode may be a desirable design objective.

47. The lowest-order mode is designated TEM_{00} (‘TEM’ stands for transverse electromagnetic, from microwave terminology, and the subscript ‘00’ represents the mode number).

48. Solid-state lasers generally operate with several modes and irregular output beam shape, but Q-switching (see paragraph 34 et seq*.)* quenches the higher-order modes of oscillation and greatly improves beam quality. Gas lasers are naturally free of higher-order modes.

49. For the best-known example of a gaussian energy distribution, the *beam divergence* is defined (for laser safety assessment) at the 1/*e*-peak radiant intensity (or integrated radiant intensity) points, containing approximately 63 per cent of the energy. This is illustrated in Fig. 1-11, and is compared with the beam divergence which is typically used by manufacturers and given by the $1/e^2$-peak intensity points, containing approximately 86 per cent of the energy.

50. Although the achievement of a gaussian-shaped laser beam output profile is not often met with practical lasers, it serves as a useful theoretical basis for safety calculations. TEM_{00} is the only mode for which a calculation can be readily performed, connecting the beam diameter with range from the laser (from which the radiant exposure or irradiance with range can be obtained). It achieves the tightest degree of collimation, thus producing the highest radiant intensity, and represents a worst-case analysis which may be necessary if doubt exists as to the beam quality or the true diameter of the beam.

51. The natural change in the diameter of a gaussian laser beam with distance along the direction of propagation is illustrated in Fig. 1-12. This shows a region close to the laser in which the laser beam is almost parallel (the *near-field),* while beyond this region the laser beam divergence is treated as being constant *(the far-field).* A mathematical description of the variation of the beam diameter with distance is found in Annex 3A, paragraph 50 et seq.

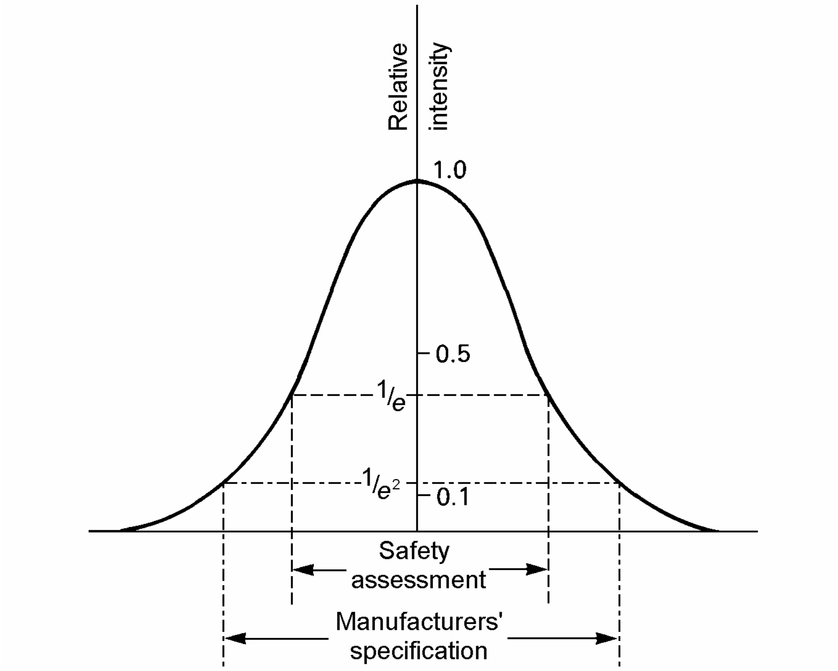

Fig. 1-11 A gaussian beam profile

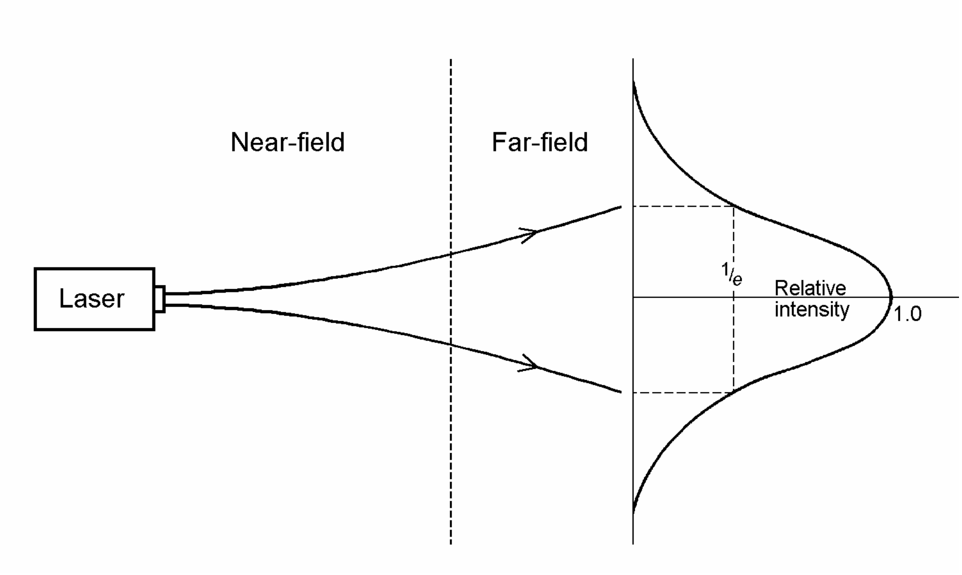

Fig 1-12 Variation of gaussian beam diameter with distance

52. The design of a laser system would normally include some form of optics to adjust the size and shape of the laser beam produced by the laser cavity, in order to achieve particular performance characteristics. For typical military lasers, the optics used are commonly in the form of a telescope which expands the natural laser beam diameter and reduces the initial beam divergence, thus producing a wider less-divergent laser beam. However, more-complex optics may be used in order to produce a convergent laser beam or to change the spatial profile of the laser beam (e.g. to rectangular).

LASER BEAM PROPAGATION THROUGH THE ATMOSPHERE

53. Simple analysis of the laser beam profile assumes that the laser beam intensity decreases only by the natural beam divergence, and does not take into account additional degradation through losses occurring in the passage through the atmosphere which are greater with lower altitude.

54. The main sources of loss in intensity from the atmosphere (atmospheric attenuation) are *absorption, scattering, atmospheric turbulence.*

55. Absorption and scattering are caused by the air molecules that lie within the laser beam path. There are several types of aerosols, such as water droplets, that are encountered in haze, mist, fog, cloud and rain; there are also solid particulates, such as dust, fumes and smoke. Absorption and scattering do not materially contribute to changes in beam profile.

56. The transmission (reciprocal of attenuation) of a laser beam through the atmosphere is an irregular and complex function of the wavelength, as shown in Fig. 1-13. There are transmission windows notably in the far-infrared, near-infrared and visible regions of the spectrum but there are also regions of strong absorption. The figure shows the differences in transmission for the levels of visibility, i.e. 5 km and 20 km for a particular location, viz. a coastal path, but the same general features apply for other geographical locations. The presence of smoke and fumes would have a detrimental effect and diurnal variations associated with local terrain conditions can also be expected, making prediction very difficult. In general, attenuation is less over the sea.

57. Atmospheric temperature differences produce atmospheric turbulence causing variation in the refractive index experienced by the laser beam. The effect is similar to the well-known ‘miraging’ over hot deserts. It causes the shape of the laser beam to change from gaussian to a structure of peaks and valleys; *scintillation* is the name given to this effect and account of it must be taken when calculating laser hazard distances as it may increase them (see Annex 3A). In certain cases, atmospheric turbulence can broaden the beam resulting in a reduction in the hazard through lowering or loss of effectiveness.

58. Very high power, *convergent* laser beams may be affected by a process called *thermal blooming.* At or near the focus of the beam, the air becomes heated to such a degree that refractive index gradients are set up, which act as a distributed lens of negative power to cause the beam to defocus.

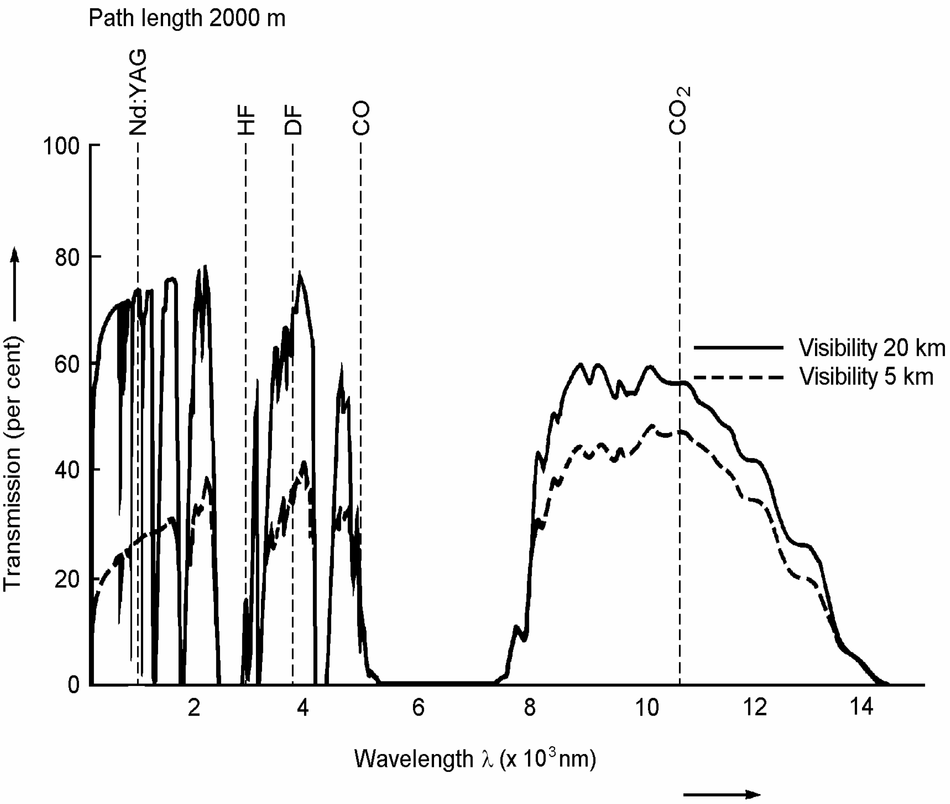

Fig. 1-13 Atmospheric transmission

CHAPTER 1 ANNEX A

CHRONOLOGY OF LASER HISTORY

CHRONOLOGY OF EVENTS IN LASER DEVELOPMENT

Date	*Event*
1916	Einstein presented theory of quantum optics, the basis of stimulated (laser) emission.
1954	First practical demonstration of stimulated emission at a wavelength of 1.25 cm and MASER (microwave amplification by stimulated emission of radiation).
1960	First LASER demonstration using a ruby crystal at 694 nm.
1961	First gas laser demonstration with helium-neon.
1961	First neodymium laser demonstration.
1962	First semiconductor laser demonstration.
1963	First carbon dioxide laser demonstration.
1964	First argon-ion laser demonstration.
1966	First liquid dye laser demonstration.
1975	First rare-gas halide excimer laser demonstration.
1976	First free electron laser demonstration.
1985	First X-ray laser demonstration.
1989	First diode-pumped laser demonstration.

CHRONOLOGY OF EVENTS FOR IN-SERVICE LASERS

Date	*Event*
1970	Founding of the MLSC
1974	Ruby TLS installed on Chieftain MBT.
1974	Nd:YAG LRMTS into Service.
1975	Nd:YAG LP7 into Service.
1976	Nd:YAG LTM into Service.
1976	Nd:YAG LP6 into Service.
1981	Nd:YAG TLS installed on Challenger MBT.
1988	Nd:YAG TIALD fitted to aircraft.
1990	Nd:YAG GPEOD trialled on frigates.
1993	Raman-shifted Nd:YAG LRMTS trialled on aircraft.
1995	GaAs DFWES introduced for weapon-simulation training.
1996	Diode lasers for communications introduced

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CHAPTER 2

LASER HAZARDS

INTRODUCTION

1. Lasers can give rise to the following hazards to the person:

Direct hazards –

a. Damage to the eye

b. Skin burns (thermal and photochemical).

Indirect hazards –

c. Electrical.

d. Chemical.

Associated hazards –

e. Fire.

f. Noise.

g. Cryogenic.

h. X-ray production.

In addition, there can be hazards to the environment.

2. Emissions from normal industrial and military lasers are unlikely to cause direct fatality, although this effect is within the capability of very high power lasers. However, there is a greater risk of a fatality occurring through electrocution from the power supply.

3. The initial cause of any type of radiation damage to biological tissue is the absorption of energy. Such damage is familiar to anyone who has experienced sunburn. The absorption of energy is a complex process that occurs at the molecular level and is dependent on the characteristics of the radiation and of the absorbing tissue. The degree of tissue breakdown can be related to the physical parameters of the radiating source, such as the wavelength, pulse duration, beam size and the length of time exposed to that source (radiant exposure).

LASER CLASSIFICATION

4. Lasers are classified in the British Standard according to the degree of eye hazard which may be presented by the laser.

5. It is the responsibility of the manufacturer to classify the product in accordance with the procedures set out in the British Standard. The classifications are applied to both lasers and products containing lasers. All laser products are assigned to one of seven classes which are detailed in the British Standard and are summarized below. Except in the case of Class 1 and Class 1M, where information may be provided in the instructions, the classification should be marked on the equipment in accordance with the British Standard.

a. *Class 1.* Class 1 lasers, which are safe under reasonably foreseeable conditions of operation. This means that if you view the beam directly, or look at it through optics that could focus light into the eye (e.g. binoculars, telescopes, weapon sights) then the laser is still safe.

b. *Class 1M*. Class 1M lasers emitting radiation with wavelength between 302.5 nm and 4 µm which are safe for direct viewing of the beam. They may, however, be unsafe if viewed with optics that focus light into the eye such as binoculars, telescopes, weapon sights etc. (the ‘M’ in ‘1M’ stands for ‘Magnifying Optics’). Class 1M lasers usually have either highly diverging beams (see Fig. 2-1 below) or well-collimated but large beams (see Fig. 2-2). The magnifying optics effectively ‘gather up’ the light and funnel it into the eye, increasing the dose that the eye receives. A Class 1 laser does not become ‘gathered’ in this way (see Fig. 2-3). Measurements carried out by the laser manufacturer determine if it is Class 1 or 1M.

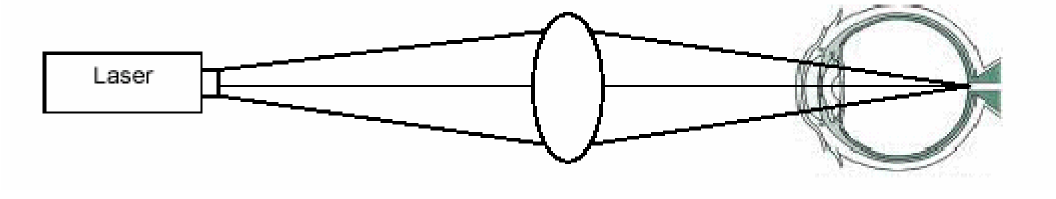

Fig. 2-1 Class 1M laser with diverging beam, viewed through a magnifying glass.

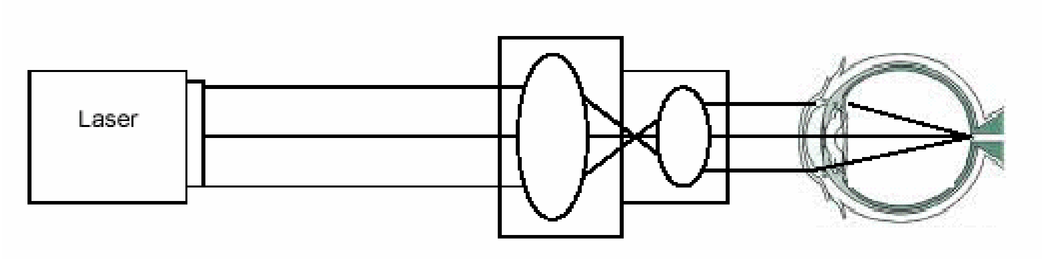

Fig. 2-2 Class 1M laser with large diameter beam, viewed through binoculars or a weapon sight.

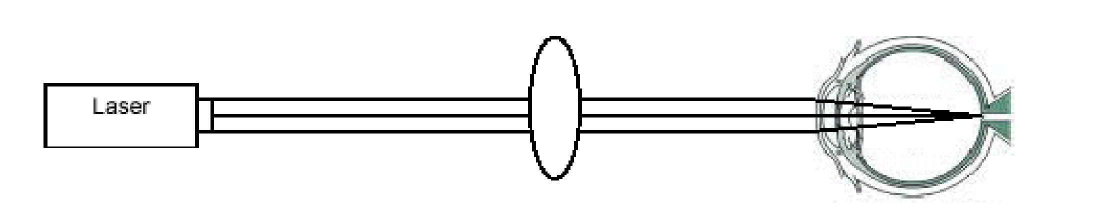

Fig. 2-3 The beam from a Class 1 (not 1M) laser is safe under any conditions, even when viewed through magnifying optics such as binoculars and weapon sights

c. *Class 2 Lasers*. Low power visible lasers (400 nm to 700 nm wavelength) with an output between 0.4 µW and 1 mW. These lasers are not safe if stared at deliberately, but eye protection is normally afforded by natural aversion responses such as blinking. This includes situations where the beam is viewed directly with optics that could focus light into the eye (e.g. magnifying glass, binoculars, weapon sights).

d. *Class 2M Lasers*. Low power visible lasers (400 nm to 700 nm wavelength). These lasers are not inherently safe but eye protection is normally afforded by natural aversion responses such as blinking. However, the aversion responses will not protect you from a Class 2M laser if you view the beam directly with optics that could focus light into the eye (e.g. magnifying glass, binoculars). The situations that could lead to this are the same as for Class 1M (see Figs. 2-1 and 2-2), but the beam from a Class 2M laser will always be visible.

e. *Class 3R Lasers*. Lasers whose output is up to a factor of five times the maximum allowed for Class 1 or, for visible lasers, Class 2. Because of the conservative nature of the limits to Classes 1 and 2, there is only a low risk of injury from direct viewing of Class 3R lasers and therefore fewer requirements for safe use of Class 3R lasers apply than for Class 3B lasers.

f. *Class 3B Lasers*. Medium power lasers. The output is hazardous if viewed directly or after reflection off a polished or wet surface (i.e. if the beam shines into the eye). Viewing diffuse reflections is normally safe. It must be emphasized that the aversion response will not normally protect the eye from injury. The beam from a Class 3B laser will only become safe after it has spread out over a considerable distance. Remember that the beam might not be visible, depending on the type of laser.

g. *Class 4 Lasers*. High power lasers. The output is hazardous to the eye if viewed directly or after reflection off polished surfaces, and may also be hazardous even after being diffused by a matt or rough surface. The laser beam only becomes safe after it has spread out over a very long distance. Some lasers in this category may be capable of causing fires, may be hazardous to skin or may produce other hazards. Many military systems such as target markers, Rangefinders etc use Class 4 lasers, most of them with invisible laser beams.

DIRECT HAZARDS

CIE wavebands

6. The International Commission on Illumination (*Commission Internationale d'Eclairage*, CIE) divides optical radiation into spectral bands according to their biological importance. A summary of the biological effects for the eye and skin is given in Fig. 2-4. Accurate wavelength boundaries of these bands are shown in Table 2-1.

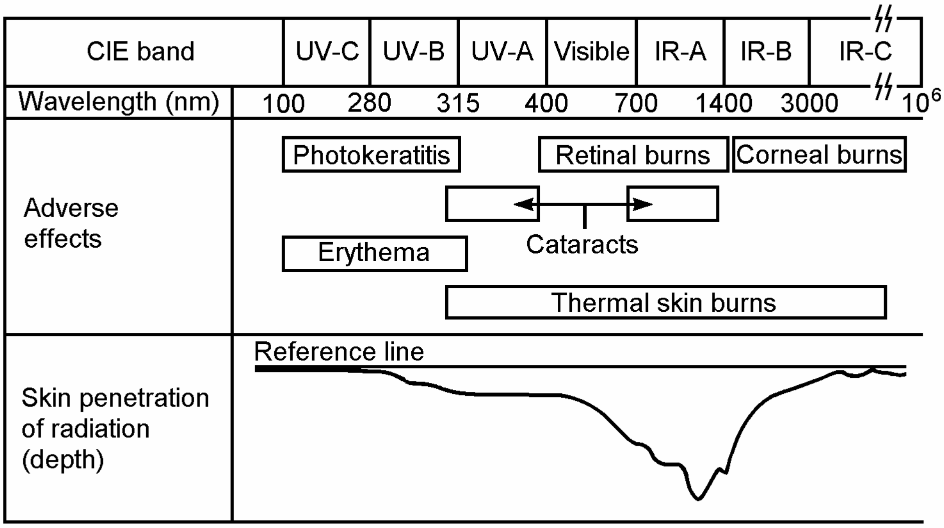

Fig. 2-4 Biological Effects

Table 2-1 CIE waveband limits

CIE band	Wavelength limits (nm)
Ultraviolet-C	100 to 280
Ultraviolet-B	280 to 315
Ultraviolet-A	315 to 400
Visible	400 to 700
Infrared-A	700 to 1400
Infrared-B	1400 to 3000
Infrared-C	3000 to 10^6

7. Although the CIE defined wavebands refer to the biological effects of incoherent (ordinary) light, they are a satisfactory guide to laser hazard assessment.

8. It should be noted, however, that high-power pulsed lasers can give rise to biological damage which is not normally associated with ordinary light. Such a laser beam can produce intense ionization within the eye tissue, resulting in the generation of plasma and subsequent tissue damage by associated thermo-mechanical effects. In general, pulsed lasers are more injurious to the eye than CW lasers for a given total energy, because of the extra difficulty the eye has in conducting the absorbed heat away in the very short period of time that the pulse lasts.

Hazards to the eye

9. The penetration of the eye by the different CIE wavebands and, by inference, laser radiation within these bands is illustrated in Fig. 2-5.

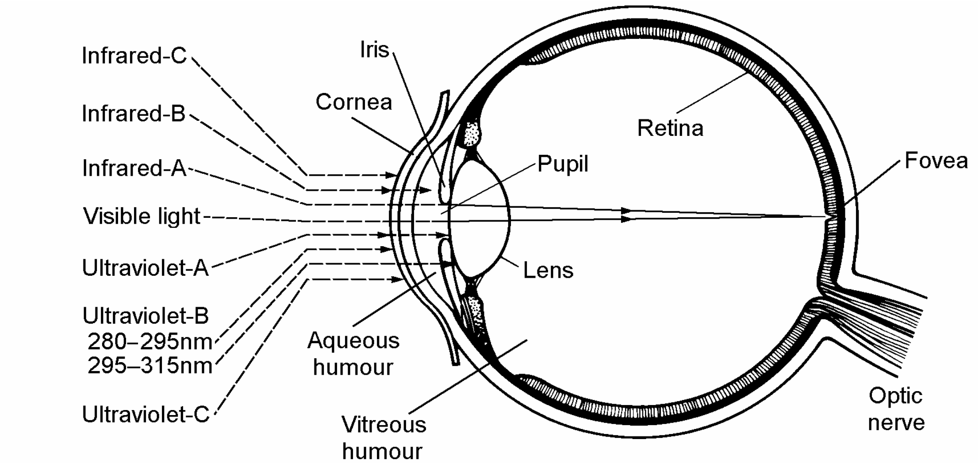

Fig. 2-5 Penetration of optical radiation in the eye

10. Thus,

a. Infrared-C is primarily absorbed in the cornea, while Infrared-B penetrates to the aqueous humour — both may cause corneal burns.

b. Ultraviolet-A primarily affects the lens in the eye, where it may cause delayed (>10 years) production of cataracts.

c. Ultraviolet-B is largely absorbed by the cornea where it causes burning of the skin and photochemical effects on the eyes producing, after a latent period, a painful kerato-conjunctivitis which most commonly occurs as ‘arc welding eye’ or ‘snow blindness’. The condition generally resolves with treatment, within 24 hours. However, photokeratitis caused by Ultraviolet-B will not heal if the corneal epithelial layer is penetrated. Longer-wavelength Ultraviolet-B (295 to 315 nm) can reach the crystalline lens where it may initiate cataractogenesis. Wavelengths between 200 nm and 320 nm are commonly referred to as the actinic ultraviolet region.

d. Ultraviolet-C, like Infrared-C, is absorbed in the cornea where it may cause damage.

e. Laser radiation in the Visible and Infrared-A regions poses the greatest hazard. It passes through the apparatus of the eye with very little absorption and is then focused with a very high degree of convergence to a very small spot onto the retina, and can result in permanent damage. The actual spot size depends upon the range at which the eye is focused, but could be as small as 10 µm, and the intensity of radiation could approach nearly half a million times greater than at the cornea. The effect is particularly severe if the eye is relaxed, i.e. focused at infinity and looking directly at the laser source: in this situation, the laser beam is focused onto the fovea of the retina and causes loss of both chromatic and detailed vision. Glancing laser radiation focuses onto other parts of the retina, on which the effects may not be so pronounced.

11. A detailed analysis of the absorption of optical radiation is shown in Fig. 2-3.

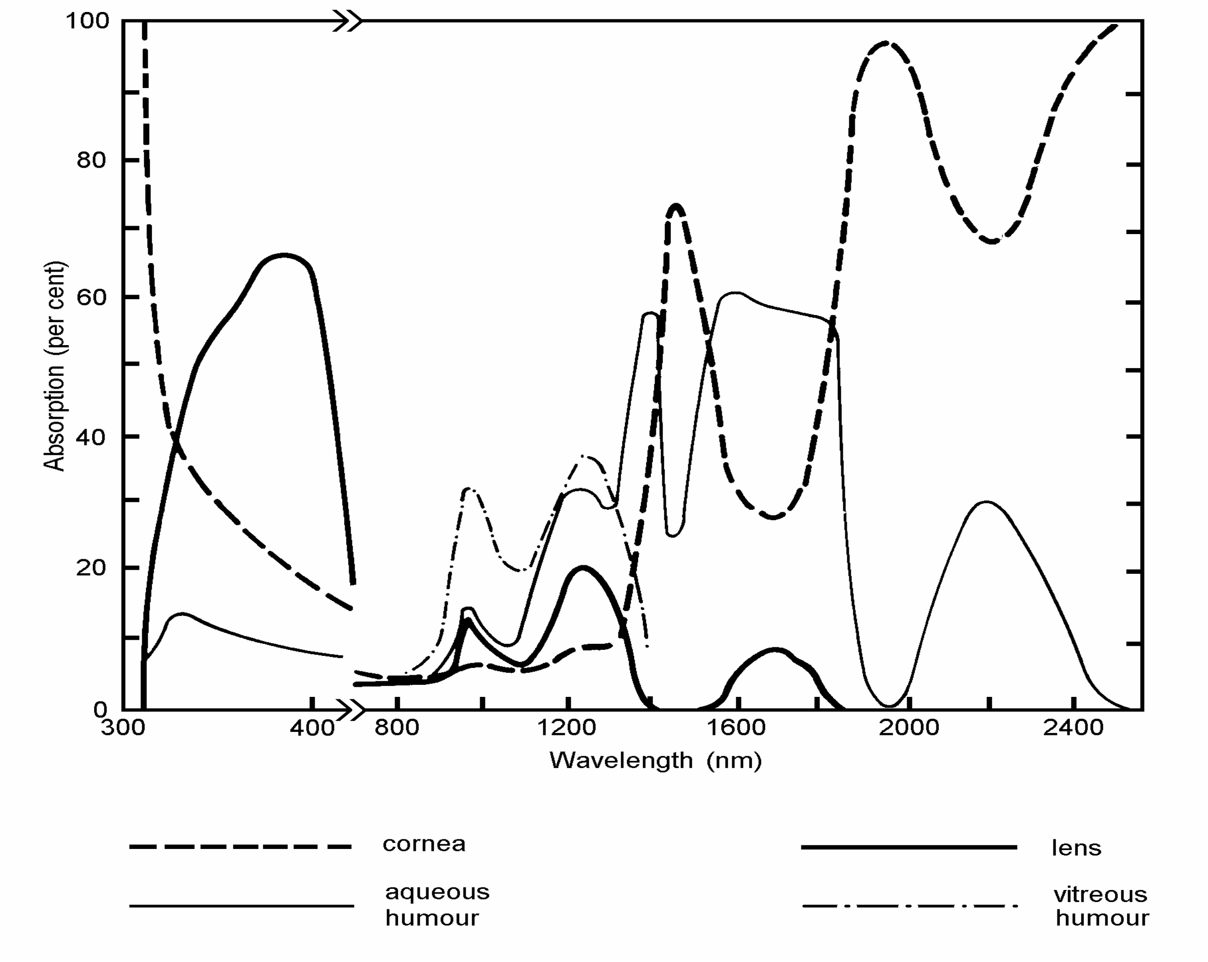

Fig. 2-6 Spectral absorption in the human eye

12. Fig. 2-6 shows the absorption in different parts of the ocular structure as a function of a laser wavelength. Note that there is very little absorption in the Visible region, hence the break in the curves. Note also the strong absorption by the lens in the Ultraviolet-A region (315 to 400 nm) and the absorption by the vitreous humour in the 860 to 1350 nm infrared region. Regions of strong absorption at longer wavelengths infer elevated temperatures and the heat which is generated can be conducted to closely-adjacent organs, causing damage. For example, the heat generated in the cornea could be conducted to the aqueous humour and heat generated in the iris could be conducted to the lens, possibly resulting in a cataract.

13. A transient reduction in visual performance can occur at irradiances lower than those required to cause permanent retinal damage. A number of terms are used to describe the various effects:

a. *Glare*. This is caused by scattering of visible radiation within the eye, resulting in the appearance of a veil of light over the image of an object, or by excessive exposure of the eye to visible radiation (as from the Sun). Although retinal illumination is increased, the image contrast is decreased and so detailed discrimination becomes more difficult.

b. *Flashblindness*. This can be caused by an intense flash of light, leading to an immediate but temporary reduction (perhaps total) in visual performance, and which can persist for a few seconds. Disorientation is also possible. An afterimage can remain after the flashblindness subsides (see below).

c. *Afterimage*. These appear in the visual field as an area of the same size and shape of the flash which caused it, and they may persist for a period up to a few days. The colour and brightness of an afterimage can change with time, and according to the background being viewed.

Hazards to the skin

14. There is generally no hazard to skin from Class 1, Class 2 and Class 3 lasers. When working with Class 4 lasers, injury to the skin is far less likely than retinal eye damage. The levels of visible and infrared radiation required to cause injury to the skin are quite high, at least several hundreds of watts per square metre ($W\ m^{-2}$) and depend not only upon the area of the skin absorbing the laser radiation but also upon the wavelength, the absorption depth and exposure duration. The long-term consequences of overexposure to the skin are, in the case of minor thermal burns, less severe than that to the eye.

15. The skin shares with the cornea a particular susceptibility to injury in the actinic ultraviolet spectral region. This radiation can cause sunburn (erythema) of the skin. Further, it has also been indicted as the cause of many types of skin cancer. Instead of exposure levels of several watts per square metre required to cause thermal injury, exposure levels of only microwatts per square metre delivered over several hours are required to cause sunburn. Except for the ultraviolet spectral region, laser radiation exposure is believed to cause only thermal injury to the skin.

16. The sensitivity of the skin is greatly increased by certain photo-sensitizing chemicals and by previous exposure to specific wavelength bands (generally in the near-ultraviolet and visible portion of the spectrum). The light-sensitizing substances can occur in the skin as a result of certain diseases, medical treatments or cleaning agents.

17. The penetration of the skin as a function of wavelength is shown in Fig. 2-4. Note that Infrared-A radiation penetrates to the greatest depth.

INDIRECT HAZARDS

Electrical hazards

18. Almost all laser power supplies have the potential to cause severe electrical shock; an exception is the power supply for a semiconductor laser. Pulsed lasers are particularly dangerous because of their use of capacitor banks to store energy. Electrical safety precautions should always be followed when using any electrical or electronic equipment. The most likely exposure to an electrical hazard is during set up and service when protective panels are often removed. Serious electrical hazards exist with most ‘breadboard’ lasers in use in research laboratories.

Chemical and resulting hazards

19. Lasers sometimes contain highly-toxic materials; for example, hydrogen chloride in HCl/xenon lasers and the solvents used in dye lasers such as dioxane and dimethyl sulphoxide (DMSO). The laser dyes used are complex organic molecules that are generally highly toxic or carcinogenic. Care should always be exercised when handling or preparing solutions. Some solvents such as DMSO are able to transport dyes into the skin.

20. Potentially-hazardous airborne contaminants are often released into the atmosphere during laser material processing, these being produced by the vaporization of the target material when irradiated by high energy laser beams. Laser welding or cutting of metals can form many of the metal oxides and other fumes encountered during conventional welding activities. Harmful compounds such as hydrogen cyanide and benzene may be given off by some polymers, and bacteria and viruses may be liberated during laser surgery. Adequate ventilation and extraction facilities should therefore be provided.

21. In some wavelength-shifting mechanisms, such as Raman shifting, high-intensity laser beams are focused into a nonlinear medium. Sometimes unstable reactive compounds are produced due to the heating by the laser radiation and decomposition of the nonlinear medium: these may be hazardous. It should also be noted that in some designs, the fundamental radiation is allowed to exit giving rise to a laser hazard at more than one wavelength.

ASSOCIATED HAZARDS

22. Some Class 4 laser systems may have sufficient output to represent a fire hazard (e.g. high-power carbon dioxide continuous wave systems). Appropriate flame-retardant materials should be used with these lasers and fire extinguishers should be readily available. Flammable materials should always be kept out of the beam path. Plastics such as those found in wire insulation are particularly vulnerable to lasers operating at wavelengths outside the visible spectrum.

23. It should be noted that some components such as capacitor banks, high-pressure arc lamps and filament lamps can explode when they fail. Satisfactory housings should be used to enclose these types of components. In some laser systems there are chemical reactants present which may give rise to explosive reactions.

24. The common problems associated with the use of compressed gases are: inadequate exhaust and ventilation, free-standing gas cylinders, gases incorrectly stored and inadequate provisions for shutoff valves.

25. Occasionally, there may be a noise hazard resulting from gas-dynamic laser exhausts and high-power pulsed laser discharges, such as excimers. Where this type of hazard exists, noise control may be necessary and hearing protection is essential for all personnel who may be exposed to high noise levels.

26. Liquid nitrogen and other cryogenic fluids are used in the cooling systems of certain lasers. Cryogenic fluids can cause severe burns and, when they evaporate, they displace breathable oxygen. Therefore, cryogenic fluids should only be used in well-ventilated areas.

27. Both protective clothing and face shields should be used when working with large quantities of liquified gases. Safety procedures are required when using gas canisters or when using cryogenic dewar flasks to prevent the occurrence of a serious accident. However, the quantities of liquid nitrogen used in cooling the infrared-sensitive detectors commonly used with infrared laser systems are so small that they do not normally pose serious health hazards.

28. Radiation, other than that emitted as the output laser beam, may be produced by other components within the laser system such as power supplies, plasma tubes and discharge lamps. This collateral radiation may cover many parts of the electromagnetic spectrum; including X-rays, ultraviolet, visible, infrared, microwave and radio-frequency emissions. Also when dealing with focused high-power pulsed laser beams, plasmas may be generated within the focal plane for sufficiently-high intensities (10^{16} W m^{-2}).

29. High-voltage (> 5 kV) power supplies may generate X-rays, while flashlamps and discharge tubes can generate collateral ultraviolet and visible radiation and Q-switches generate radio-frequency emissions. Sufficient radiation shielding is normally installed around high-voltage equipment to prevent the leakage of potentially-hazardous levels of X-rays. However, risks exist in removing the shielding (in addition to increasing the possible laser hazard) and reference should be made to regulations relating to the hazards of ionizing radiation (JSP 392)

30. Attention must be paid at all times to the document *Control of Substances Hazardous to Health Regulations* (COSHH).

CHAPTER 2 ANNEX A

LASER CLASSIFICATIONS BASED ON BS EN 60825:1994 AND A11:1996

1. In the next few years there will be a significant number of lasers which will be classified according to the standard BS EN 60825:1994 + A11:1996 which was withdrawn on 1st January 2004. Whilst the use of this classification system for lasers which were developed before this date is acceptable, all new lasers must be classified according to the definitions in Chapter 2.

2. For the purposes of clarity the definitions of these older classifications are given below, they are not to be used in Laser Safety Papers unless they comply with the restriction above in paragraph 1.

a. *Class 1.* The lowest-powered lasers are Class 1 lasers. This group is normally limited to very low power semiconductor lasers or totally-enclosed laser systems. These lasers are not considered hazardous even if the output laser beam is collected by 50 mm collecting optics and concentrated into the pupil of the eye.

b. *Class 2.* Class 2 lasers operate in the visible part of the spectrum, i.e. in the wavelength range 400 to 700 nm. Deliberate direct viewing for longer than 0.25 second may be hazardous but protection is normally afforded by the eye's natural aversion response to bright light (including the blink reflex). There is no increase in hazard from this class of laser when optical viewing aids are used.

c. *Class 3A.* This class represents an extension of Class 2 for visible light, but also covers other wavelengths. For visible light, unaided direct viewing of these devices is still protected by the blink and aversion responses, but the use of optical viewing aids may be hazardous.

d. *Class 3B.* Class 3B concerns lasers of all wavelengths where direct viewing is hazardous, but viewing of diffuse reflections is generally safe.

e. *Class 4.* Class 4 lasers are capable of causing serious injury to both eye and skin, and may produce diffuse reflections that are hazardous to the eye. They may also constitute a fire hazard.

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CHAPTER 3

LASER HAZARD ASSESSMENT

WARNING

Errors in the calculation of laser hazard distances could have serious safety implications.

Official hazard distances may only be established or modified by MLSC-approved procedures.

Introduction

1. Chapter 2 introduces the concept of laser classification and concludes that only Class 1 lasers are deemed to be unequivocally safe for both naked-eye and visually-aided viewing during normal use. In all other categories of classification, a hazard to the unprotected eye and/or skin may occur. The purpose of this chapter is to identify and quantify eye and skin hazards in terms of hazard criteria and worked examples.

2. The manufacturer normally provides the laser parameters which are required for classification purposes in compliance with the British Standard. However, there are currently no British Standard requirements for the measurement of additional parameters which are necessary for hazard evaluation. Care must therefore be taken in the values assumed for the various parameters used in hazard evaluation: actual equipment characteristics can vary from specification values and they can also vary with time. It cannot be assumed that laser performance deteriorates with time, and regular testing of a laser system is recommended.

3. Two methods of hazard evaluation are adopted, namely *deterministic hazard assessment* and *probabilistic hazard assessment*.

Deterministic hazard assessment

4. Deterministic hazard assessment is based upon the concept of *Maximum Permissible Exposure* (MPE), which is defined as that level of laser radiation to which a person may be exposed without suffering adverse health effects. However, MPE levels are set well below observable injury criteria and, as such, are regarded to be highly pessimistic. They are the accepted international standard.

5. From these MPE levels a basic hazard distance is calculated and is called the *Nominal Ocular Hazard Distance* (NOHD), which is defined as the distance, in a vacuum, along the axis of the laser beam beyond which it is safe to view the laser with the naked eye. An analogous distance for skin may be called the *Nominal Skin Hazard Distance*. These definitions ignore atmospheric effects and, in the case of the eye, the use of visual aids: more-general definitions called the *Ocular Hazard Distance* (OHD) and *Skin Hazard Distance* take into account these additional features.

6. The deterministic assessment described in Annex 3A conforms to, but extends, that of other standards, and is designed for the benefit of Service use without compromising laser safety. It is suitable for static ground-based lasers firing at static ground targets.

7. Annex 3A is designed to enable a mathematically-competent person to undertake self-calculation of hazards.

Probabilistic hazard assessment

8. The deterministic assessment model is less suitable for highly-mobile airborne laser platforms, particularly in air-to-ground engagements. In these scenarios, the use of MPE-based criteria can lead to impracticably-large ground laser hazard footprints which may extend outside the boundary of any UK Range, with consequent problems in meeting military training requirements for the use of laser devices.

9. In such cases an alternative method, which does not compromise laser safety, is to adopt probabilistic hazard assessment. Such an approach is based upon the concept of an acceptably-low probability that a casual observer outside the Range boundary is irradiated and receives a minimally-measurable level of eye damage. This level of ocular damage is called the *Minimum Ophthalmoscopically Visible Lesion* (MOVL), and the associated size of lesion on the retina is 30 μm, being the smallest limit which can be observed with an ophthalmoscope. MOVL replaces MPE in probabilistic hazard assessment.

10. There is no equivalent to the NOHD in the probabilistic model. The maximum acceptable probability of an observer suffering a MOVL can be used to define a *Laser Hazard Area Trace* (LHAT), inside which the risk of ocular damage is deemed to be unacceptable. Typically, this probability has been chosen to be 10^{-8} per engagement to give realistic pessimism without inflicting a higher level of ocular damage and compares favourably with other military weapon risk criteria. It should be stressed that care was taken in the choice of this probability, so as not to invoke higher levels of risk of receiving retinal injury than those which are implied by irradiation at the level of the MPE in deterministic modelling.

11. A comparison is made between the deterministic and probabilistic assessments in Fig. 3-1 for a particular air-to-ground engagement. The deterministic trace is achieved by sweeping the OHD through possible pointing directions (which includes buffer zones), as in chapter 6, paragraph 15. The contrast between the 'broad-brush' overly-pessimistic approach of the deterministic model and the realistically-pessimistic approach of the probabilistic model is clearly revealed.

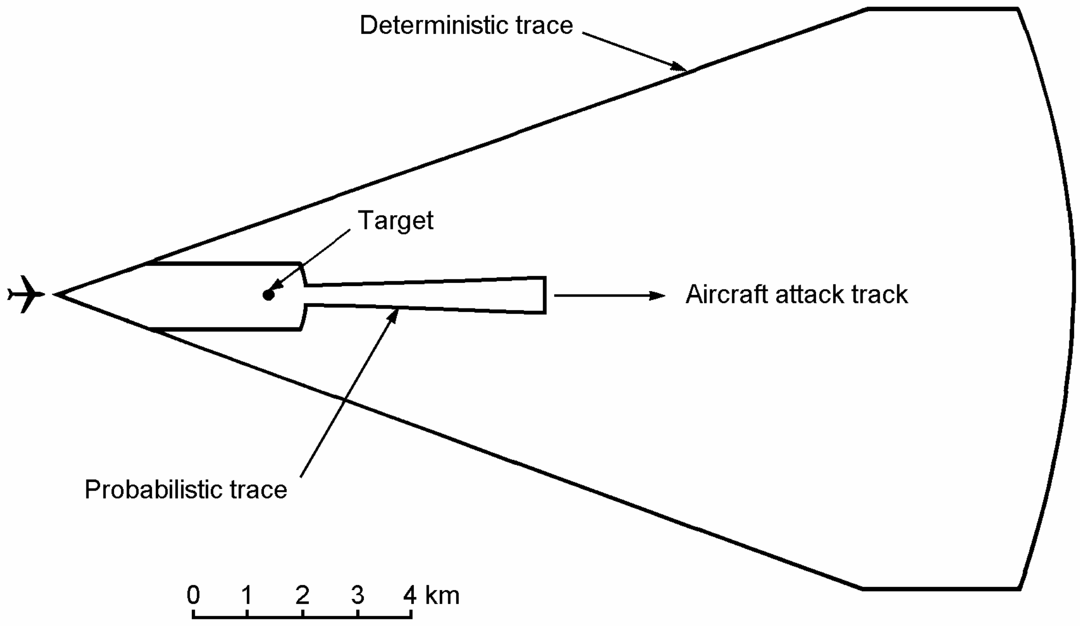

Fig. 3-1 Deterministic and the probabilistic LHATs

12. The MLSC-approved probabilistic approach (described in Annex 3B) has been developed for a range of air-to-surface, ground-to-air and ground-to-ground scenarios for the benefit of Service training with laser devices, and has STANAG 3606 recognition.

13. It should be noted, however, that the calculation of OHDs should still be included in a Laser Safety Paper to provide a simple guide to the extent of a laser's hazard.

14. Whereas the deterministic modelling in Annex 3A can be used by a mathematically-competent person, the probabilistic approach in Annex 3B generally requires specialist treatment and advice should be sought in the first instance from the MLSC.

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CHAPTER 3 ANNEX A

DETERMINISTIC LASER HAZARD ASSESSMENT

INTRODUCTION

1. The aim of this annex is to help the user through the various stages of laser hazard evaluation. This is achieved through worked examples and flowcharts, with reference to an example laser with the following characteristics:

Wavelength	1064 nm
Total pulse energy	90 mJ
Peak pulse power	4.5 MW
Pulse length	20 ns
Pulse repetition frequency	Single pulse or 20 Hz
Beam diameter	20 mm
Beam divergence	0.5 mrad
Beam train duration	20 s

The system's design is based on a laser cavity of 2.5 mm diameter with an optical telescope which expands the initial beam diameter by a factor of 8.

The system is also capable of being fitted with a transmitting diffuser, of 70 per cent transmittance, which produces a perfectly-diffuse emission 20 mm in diameter.

2. The British Standard assumes that the laser emerges from the laser system in the far-field. However, unless confirmed by measurement, this assumption can underestimate the ocular hazard distances. Therefore, if there is doubt, then it must be assumed that the laser beam emerges in the near-field (see paragraph 50 *et seq.*).

3. Similarly, the calculation of ocular hazard distances typically assumes that the laser beam profile is gaussian (TEM_{00}). This is frequently not the case, and care must be taken in applying the formulae given. The instructions in this annex apply only to divergent laser beams; for convergent beams, advice must be sought from the MLSC.

MAXIMUM PERMISSIBLE EXPOSURE

4. The Maximum Permissible Exposure (MPE) is defined as that level of radiation to which a person may be exposed without suffering observable adverse health effects. In STANAG 3606, the term ‘Protection Standard’ is used. The values of MPE should be used as guides in the control of exposure and not be regarded as precise lines between what is safe and what is dangerous.

5. The MPEs to be applied are those specified in the British Standard. Tables 3A-1 and 3A-2 give the BS EN 60825:1994 Amendments 1, 2 & 3 MPEs for ocular and skin irradiation to a single laser pulse or a single burst of CW energy. Table 3A-3 details time-dependent and wavelength-dependent factors, which are used in those tables (such as C_1 and T_1). If these tables differ from the British Standard (because of subsequent revision), then refer to the MLSC.

Table 3A–1 Maximum Permissible Exposure at the cornea for direct ocular exposure to laser radiation

Exposure Time t (s) / Wave-Length λ (nm)	10^{-13} to 10^{-11}	10^{-11} to 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to 1.8×10^{-5}	1.8×10^{-5} to 5×10^{-5}	5×10^{-5} to 1×10^{-3}	1×10^{-3} to 10	10 to 10^2	10^2 to 10^3	10^3 to 10^4	10^4 to 3×10^4
180 to 302.5	3×10^{10} W m^{-2}		30 J m^{-2}								
302.5 to 315			C_1 J m^{-2} ($t \leq T_1$) C_2 J m^{-2} ($t > T_1$)					C_2 J m^{-2}			
315 to 400			C_1 J m^{-2}					10^4 J m^{-2}		10 W m^{-2}	
400 to 700	1.5×10^{-4} C_6 W m^{-2}	2.7×10^4 $t^{0.75}$ C_6 J m^{-2}	5×10^{-3} C_6 J m^{-2}		$18\ t^{0.75}$ C_6 J m^{-2}		400 to 600 nm[c]	Retinal photochemical hazard 100 C_3 J m^{-2} using γ_p = 11 mrad	1 C_3 W m^{-2} using γ_p = 1.1 $t^{0.5}$ mrad		1 C_3 W m^{-2} using γ_p = 110 mrad
								AND[c]			
							400 to 700 nm[c]	Retinal thermal hazard ($t \leq T_2$) 18 $t^{0.75}$ C_6 Jm^{-2} ($t > T_2$) $\alpha \leq 1.5$ mrad: 10 W m^{-2} $\alpha > 1.5$ mrad: 18 C_6 $T_2^{-0.25}$ W m^{-2}			
700 to 1050	1.5×10^{-4} C_4 C_6 J m^{-2}	2.7×10^4 $t^{0.75}$ C_4 C_6 J m^{-2}	5×10^{-3} C_4 C_6 J m^{-2}		18 $t^{0.75}$ C_4 C_6 J m^{-2}			($t \leq T_2$) 18 $t^{0.75}$ C_4 C_6 C_7 J m^{-2} ($t > T_2$) $\alpha \leq 1.5$ mrad: 10 C_4 C_7 W m^{-2} $\alpha > 1.5$ mrad: 18 C_4 C_6 C_7 $T_2^{-0.25}$ W m^{-2}			
1050 to 1400	1.5×10^{-3} C_6 C_7 J m^{-2}	2.7×10^5 $t^{0.75}$ C_6 C_7 J m^{-2}	5×10^{-2} C_6 C_7 J m^{-2}			90 $t^{0.75}$ C_6 C_7 J m^{-2}					
1400 to 1500	10^{12} W m^{-2}		10^3 J m^{-2}				5600 $t^{0.25}$ J m^{-2}	1000 W m^{-2}			
1500 to 1800	10^{13} W m^{-2}		10^4 J m^{-2}								
1800 to 2600	10^{12} W m^{-2}		10^3 J m^{-2}				5600 $t^{0.25}$ J m^{-2}				
2600 to 10^6	10^{11} W m^{-2}		100 J m^{-2}	5600 $t^{0.25}$ J m^{-2}							

a. The MPEs for exposure times below 10^{-9} s and for wave lengths less than 400 nm and greater than 1400 nm have been derived by calculating the equivalent irradiance from the radiant exposure limits at 10^{-9} s. The MPE s for exposure times below 10^{-13} s are set to be equal to the equivalent irradiance values of the MPEs at 10^{-13} s.

b. The angle γ_p is the limiting angle of acceptance for the measuring instrument

c. In the wavelength range between 400 nm and 600 nm, dual limits apply and the exposure must not exceed either limit applicable. Normally photochemical hazard limits only apply for exposure duration’s greater than 10 s; however, for wavelengths between 400 nm and 484 nm and for apparent source size between 1.5 mrad and 82 mrad, the dual photochemical hazard limit of 100 C_3 J m^{-2} shall be applied for exposures greater than of equal to 1 s.

Table 3A-2 Maximum Permissible Exposure of skin to laser radiation [1)]

Wavelength λ (nm) \ Exposure Time t (s)	< 10^{-9}	10^{-9} to 10^{-7}	10^{-7} to 10^{-3}	10^{-3} to 10	10 to 10^3	10^3 to 3×10^4
180 to 302.5	3×10^{10} W m^{-2}	30 J m^{-2}				
302.5 to 315		C_1 J m^{-2} ($t < T_1$) C_2 J m^{-2} ($t > T_1$)			C_2 J m^{-2}	
315 to 400		C_1 J m^{-2}			10^4 J m^{-2}	10 W m^{-2}
400 to 700	2×10^{11} W m^{-2}	200 J m^{-2}		$1.1 \times 10^4 t^{0.25}$ J m^{-2}	2000 W m^{-2}	
700 to 1400	$2 \times 10^{11} C_4$ W m^{-2}	200 C_4 J $^{-2}$		$1.1 \times 10^4 C_4 t^{0.25}$J m^{-2}	2000 C_4 W m^{-2}	
1400 to 1500	10^{12} W m^{-2}	10^3 J m^{-2}		5600 $t^{0.25}$ J m^{-2}	1000 W m^{-2} [2)]	
1500 to 1800	10^{13} W m^{-2}	10^4 J m^{-2}				
1800 to 2600	10^{12} W m^{-2}	10^3 J m^{-2}		5600 $t^{0.25}$ J m^{-2}		
2600 to 10^6	10^{11} W m^{-2}	100 J m^{-2}	5600 $t^{0.25}$ J m^{-2}			

1) There is only limited evidence about effects for exposure of less than 10^{-9} s. The MPEs for these exposure times have been derived by maintaining the irradiance applying at 10^{-9} s.

2) For exposed skin areas greater than 0.1 m^2, the MPE is reduced to 100 Wm^{-2}. Between 0.01 m^2, the MPE varies inversely proportional to the skin area.

Table 3A-3 Factors used in Tables 3A-1 and 3A-2

Parameter	Spectral region (nm)
$C_1 = 5.6 \times 10^3 \, t^{0.25}$	302.5 to 400
$T_1 = 10^{0.8(\lambda-295)} \times 10^{-15}$ s	302.5 to 315
$C_2 = 10^{0.2(\lambda-295)}$	302.5 to 315
$T_2 = 10 \times 10^{[(\alpha-\alpha_{min})/98.5]}$ s [a)]	550 to 700
$C_3 = 1$	550 to 700
$C_4 = 10^{0.002(\lambda-700)}$	700 to 1050
$C_4 = 5$	1050 to 1400
$C_5 = N^{-1/4}$ [b)]	400 to 10^6
$C_6 = 1$ for $\alpha \le \alpha_{min}$ [c)]	400 to 1400
$C_6 = \alpha/\alpha_{min}$ for $\alpha_{min} < \alpha \le \alpha_{max}$ [c)]	400 to 1400
$C_6 = \alpha_{max}/\alpha_{min} = 66.7$ for $\alpha > \alpha_{max}$ [c,d)]	400 to 1400
$C_7 = 1$	1050 to 1150
$C_7 = 10^{0.0018(\lambda-1150)}$	1150 to 1200
$C_7 = 8$	1200 to 1400

a) T_2 = 10 s for α < 1.5 mrad and T_2 = 100 s for α > 100 mrad

b) C_5 is only applicable to pulse duration's shorter than 0.25 s.

c) C_6 is only applicable to pulsed lasers and to CW lasers where thermal injury dominates.

d) The limiting angle of acceptance γ shall be equal to α_{max}, α_{min} = 1.5 mrad, α_{max} = 100 mrad

N is the number of pulses contained within the applicable duration

FACTORS AFFECTING THE MPE FOR THE EYE

Spectral region 400 to 1400 nm (single pulse/exposure)

6. In this region, the laser beam penetrates to the retina and experiences strong convergence, thus increasing the intensity by some one hundred thousand times.

7. *Point-source viewing*. A point source is defined as one, within the spectral region of 400 to 1400 nm, that subtends an angle, α, at the observer's eye which is less than a minimum angle α_{min} defined as

$$\alpha_{min} = \begin{cases} 1.5 \text{ mrad}, & \text{for } t < 0.7 \text{ s} \\ 2t^{0.75} \text{ mrad}, & \text{for } 0.7 < t \le 10 \text{ s} \\ 11 \text{ mrad}, & \text{for t} > 10 \text{ s} \end{cases} \qquad \text{Equation (1)}$$

where *t* is the exposure time.

8. *Extended-source viewing*. An extended source is defined as one, within the spectral region 400 to 1400 nm, that subtends an angle, α, at the observer's eye which is greater than the angle α_{min} as given by Equation (1) above. This produces an image of the laser source on the retina which is larger than from a point-source laser, resulting in a lower level of radiant exposure on the retina than would a point-source laser of equal power and beam divergence. Interpretation of this definition of extended source can be difficult for non-circular sources, and advice should be sought from the MLSC in such cases.

9. *Extended-source correction factor, C_6.* The MPE for an extended source is the product of the MPE for a point source and a multiplicative factor, C_6, where

$$C_6 = \begin{cases} 1, & \text{for } \alpha \le \alpha_{min} \quad \text{(i.e. point source)} \\ \dfrac{\alpha}{\alpha_{min}}, & \text{for } \alpha_{min} < \alpha \le \alpha_{max} \\ \dfrac{\alpha_{max}}{\alpha_{min}}, & \text{for } \alpha > \alpha_{max} \end{cases} \qquad \text{Equation (2)}$$

With α_{max} = 100 mrad.

Note that this multiplicative factor is taken into account in Table 3A-1.

10. Because the angle subtended by a laser source at an observer is dependent on the distance between the source and the observer, the extended source MPE is also dependent on distance; and there is a maximum distance, R_1, at which the source can be treated as being extended: this is given by

$$R_1 = \frac{d}{\alpha_{\min}} \qquad \text{Equation (3)}$$

where

d = Diameter of the laser source (m)

$\alpha_{\min}$ = Minimum angular subtense of the source at the observer's eye (rad), as defined in Equation (1)

The extended-source MPE at a distance of R_1 is then identical to the point-source MPE.

Example 1

Calculate the MPE for a single pulse from the point-source example laser.

Table 3A-1 is used. The table is entered using the wavelength (1064 nm) and the pulse length (20 ns). Thus:

$$\begin{aligned} \text{MPE} &= 5 \times 10^{-2} C_6 C_7 \text{ J m}^{-2} \\ &= \underline{5 \times 10^{-2} \text{ J m}^{-2}} \end{aligned}$$

as C_6 = 1 point-source viewing and C_7 = 1 for 1064 nm radiation (see Table 3A-3).

Example 2

Calculate the MPE for a single pulse from the example laser which has been fitted with the transmitting diffuser, with the observer at a distance of 5 m.

The angle subtended by the diffused source at the observer is equal to

$$\alpha = \frac{0.02}{5} = 4 \times 10^{-3} \text{ mrad}$$

which is greater than $\alpha_{\min} = 1.5 \times 10^{-3}$ rad and so the extended source correction factor is

$$\begin{aligned} C_6 &= \frac{\alpha}{\alpha_{\min}} \\ &= \frac{4 \times 10^{-3}}{1.5 \times 10^{-3}} \\ &= 2.66 \end{aligned}$$

As with the previous example the MPE is given by $5 \times 10^{-2}\ C_6\ C_7$ J m^{-2} (from Table 3A-1), so that

$$\begin{aligned} \text{MPE} &= 5 \times 10^{-2} \times 2.66 \times 1 \\ &= \underline{1.3 \times 10^{-1} \text{ J m}^{-2}} \end{aligned}$$

Other spectral regions (single pulse/exposure)

11. In these spectral regions, the laser beam does not penetrate beyond the front of the eye (see Fig. 2-2) and the concept of point and extended source is irrelevant. There is no C_6 correction factor and the single pulse/exposure MPE for a specific wavelength and exposure time can be read directly from Table 3A-1.

Repetitively-pulsed lasers

12. When a laser device is repetitively pulsed, the MPE for a single pulse has to be modified to allow for the probable increase in damage due to incidence of several pulses at or near the same spot over a short period of time. The MPE for ocular exposure at wavelengths from 400 nm to 10^6 nm is determined by using the most restrictive of requirement *a*., *b*. and *c*. below. The MPE for ocular exposure at other wavelengths is determined by using the most restrictive of a. and b.

a. The exposure from any single pulse within the train shall not exceed the MPE for a single pulse.

b. The average irradiance for a pulse train of exposure duration *T* shall not exceed the MPE for a single pulse of duration *T*.

c. The exposure from any single pulse within a pulse train shall not exceed the MPE for a single pulse multiplied by the correction factor $C_5 = N^{-1/4}$ where *N* is the number of pulses in the train.

In some cases this value may fall below the MPE that would apply for continuous exposure at the same peak power using the same exposure time. Under these circumstances the MPE for continuous exposure may be used. If in doubt, advice should be obtained from the MLSC.

Exposure time for determining the eye MPE

13. For single-pulsed lasers, the exposure time used to determine the MPE from Table 3A-1 is the duration of the laser pulse.

14. For repetitively-pulsed and CW lasers, the exposure time for determining the MPE should be taken to be the maximum time inherent in the design and operation of the laser system. However, this time may be reduced (if staring is not intended) to:

a. 0.25 s for wavelengths between 400 and 700 nm.

b. 10s for wavelengths between 700 and 1400 nm.

Example 3

Calculate the MPE for direct viewing of the example laser operating at 20 Hz.

From Table 3A-1 the MPE is taken from the lowest of the following cases:

a. *Single pulse*

$$\text{MPE} = 5 \times 10^{-2}\ \text{J m}^{-2} \text{ for direct viewing}$$

b. *Average irradiance*

Exposure time is 20 s, however this can be reduced to 10 s as the wavelength lies between 700 nm and 1400 nm,

$$\text{MPE for 10 s exposure} = 90 \times 10^{0.75}\ \text{J m}^{-2} \text{ for direct viewing}$$

There are 200 pulses in 10 s, therefore

$$\begin{aligned}\text{average MPE per pulse} &= \frac{90 \times 10^{0.75}}{200} \\ &= 2.5\ \text{J m}^{-2}\end{aligned}$$

c. *MPE reduced by* $N^{-1/4}$

$$\begin{aligned}\text{MPE} &= 5 \times 10^{-2} \times 200^{-1/4} \\ &= \underline{1.3 \times 10^{-2}\ \text{J m}^{-2}}\end{aligned}$$

The conclusion is that *c.* produces the lowest value and therefore the system MPE is 1.3×10^{-2} J m^{-2} for intrabeam viewing.

FACTORS AFFECTING THE MPE FOR THE SKIN

15. MPE values for irradiation of the skin by a single laser pulse or a single burst of CW laser energy are given in Table 3A-2. These levels are for worst-case conditions and are based upon the best available information.

16. The skin MPE for a repetitively-pulsed laser is determined by using the most restrictive of *a.* and *b.* of paragraph 12.

17. The exposure time used to determine the skin MPE should be taken to be the duration of a laser pulse for single-pulsed lasers and the duration of laser fire inherent in the design and operation of the laser system for repetitively-pulsed or CW lasers.

NOMINAL OCULAR HAZARD DISTANCE

18. The Nominal Ocular Hazard Distance (NOHD) for a divergent laser beam is the distance from the laser at which the beam irradiance or radiant exposure of the laser system falls below the appropriate MPE for the unaided eye. It takes no account of atmospheric effects or the use of magnifying optics, filters or protective eyewear.

19. Advice should be sought from the MLSC when attempting to determine the NOHD for a convergent laser beam.

20. The following paragraphs detail the calculation of the NOHD for direct viewing of point and extended laser sources. Fig. 3A-1 summarises the procedure when calculating the NOHD of a laser. The considerations of reflections are detailed in paragraph 54 et seq.

Gaussian point-source lasers

21. The following equations may be used to calculate the NOHD for direct viewing of a point-source laser having a *gaussian* beam profile and where it has not been confirmed as being in the far-field on emergence:

a. For a continuous wave laser

$$NOHD = \sqrt{\frac{4P}{\pi\varphi^2 E_m}} \qquad \text{Equation (4)}$$

b. For a pulsed laser

$$NOHD = \sqrt{\frac{4Q}{\pi\varphi^2 H_m}} \qquad \text{Equation (5)}$$

where

P = Radiant power of the laser source (W)
Q = Radiant energy of the laser source (J)
φ = Laser beam divergence at the 1/*e*-peak irradiance or radiant exposure points (rad)
E_m = MPE for a continuous wave laser ($W\ m^{-2}$)
H_m = MPE for a pulsed laser ($J\ m^{-2}$)
NOHD = Nominal Ocular Hazard Distance (m)

22. Note that Equations (4) and (5) differ from their counterparts in the British Standard, and other standards, in omitting the initial laser beam diameter term '*a*'. This deletion obviates the risk of underevaluating the NOHD for some lasers at short ranges and it also facilitates the calculation of Ocular Hazard Distances (see paragraph 35) which take into account factors such as atmospheric effects and the use of magnifying optics, filters and protective eyewear.

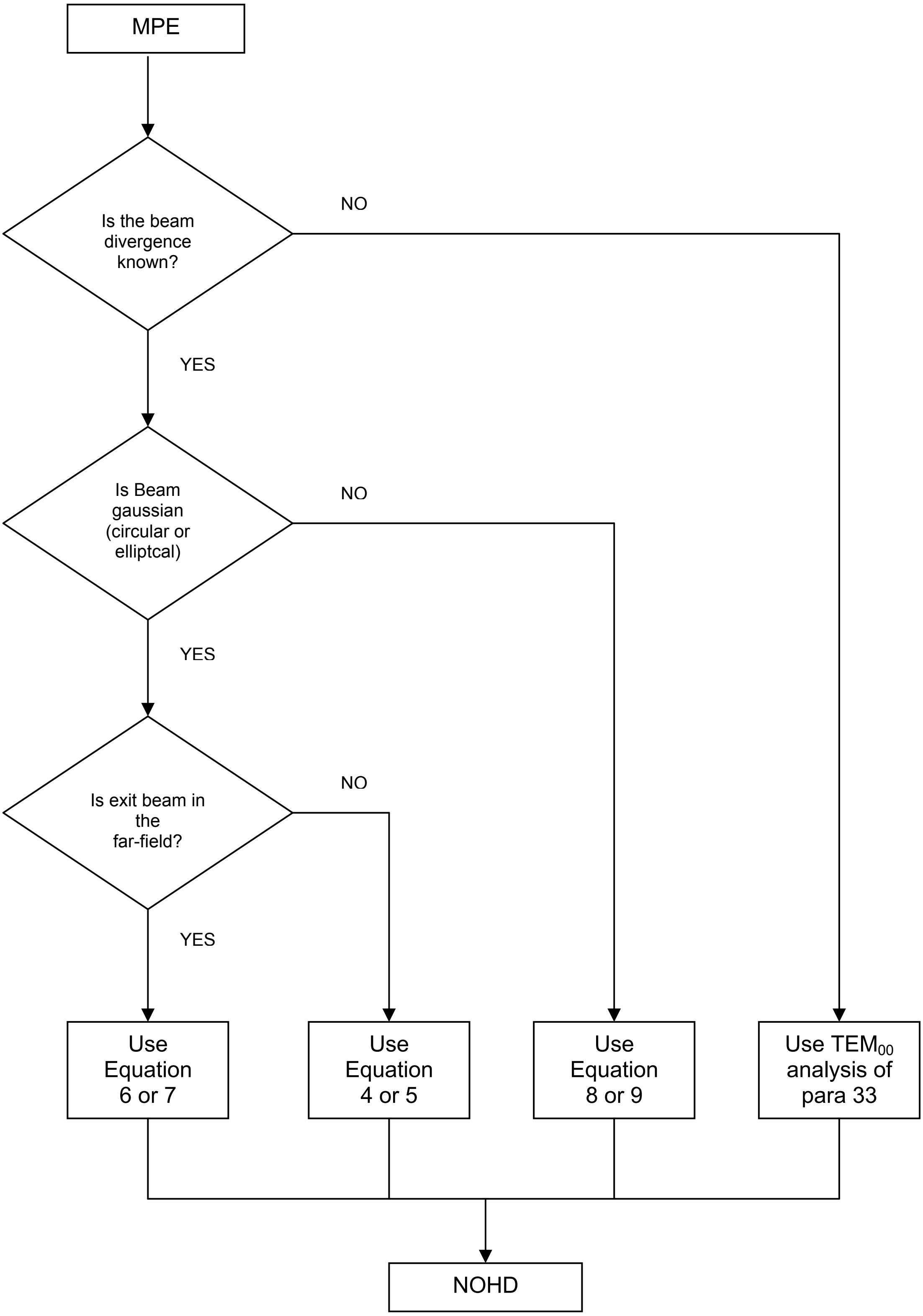


Fig. 3A-1 Calculating the NOHD of a laser

23. If it can be shown that the gaussian laser beam emerges in the far-field, then the following British Standard equations may be used:

a. For a continuous wave laser

$$NOHD = \sqrt{\frac{4P}{\pi\varphi^2 E_m}} - \frac{a}{\varphi} \qquad \text{Equation (6)}$$

b. For a pulsed laser

$$NOHD = \sqrt{\frac{4Q}{\pi\varphi^2 H_m}} - \frac{a}{\varphi} \qquad \text{Equation (7)}$$

Note that if the MPE is not exceeded at the laser aperture then the NOHD is zero by definition. This is typically evident when Equations (6) / (7) produce a negative result; in such a case, the true result is zero.

Example 4

Calculate the NOHD for a single pulse from the example laser when there is no evidence that the laser beam emerges in the far-field.

For a pulsed laser, Equation (5) applies. Therefore:

$$NOHD = \sqrt{\frac{4 \times 90 \times 10^{-3}}{\pi \times (0.5 \times 10^{-3})^2 \times 5 \times 10^{-2}}}$$

$$= \underline{3028\text{ m}}$$

If the laser is in the far-field on emergence, then the NOHD is reduced by $a/\varphi = (20 \times 10^{-3})/(0.5 \times 10^{-3}) = 40$ m. Note that for this laser, the reduction in the NOHD is small.

Non-gaussian point-source lasers

24. Equations (4)–(7) assume the laser output has a gaussian beam profile. If this is not the case the following equations should be used:

a. For a continuous wave laser

$$NOHD = \sqrt{\frac{I_P}{E_m}} \qquad \text{Equation (8)}$$

b. For a pulsed laser

$$NOHD = \sqrt{\frac{I_Q}{H_m}} \qquad \text{Equation (9)}$$

where

I_P = Peak radiant intensity (W sr^{-1})
I_Q = Peak integrated radiant intensity (J sr^{-1})
E_m = MPE for a continuous wave laser (W m^{-2})
H_m = MPE for a pulsed laser (J m^{-2})
$NOHD$ = Nominal Ocular Hazard Distance (m)

25. If I_P or I_Q are not known and cannot be measured, the values of P and Q in Equations (4)–(7) should be multiplied by 2.5 for laser systems known to have a non-gaussian beam profile.

26. If the laser beam profile approximates that of a gaussian beam but with a different peak-to-average intensity ratio (σ_{pa}) then Equations (4)–(7) may be used with P and Q multiplied by $\sigma_{pa}/2.6$.

27. If the laser beam profile is elliptical, but with each cross-section approximating that of a gaussian beam and with the beam divergence corresponding to the major and minor axes of symmetry equal to φ_x and φ_y respectively, then Equations (4)–(7) can be used with the beam divergence φ replaced by the geometrical mean of φ_x and φ_y, i.e. $\sqrt{\varphi_x \varphi_y}$.

Extended-source lasers

28. If the extended-source MPE is not exceeded, at a distance at which the source can be treated as extended (see paragraph 8), then the NOHD is zero regardless of the viewing distance considered.

29. For a *lambertian* source, this will happen for a viewing distance, R, which is less than R_1 (defined by Equation (3) of paragraph 10) and

a. For a continuous wave laser

$$R > \frac{P\cos\theta}{\pi R_1 E_m}$$

Inequality (10)

b. For a pulsed laser

$$R > \frac{Q\cos\theta}{\pi R_1 H_m}$$

Inequality (11)

where

P = Radiant power of the extended source (W)
Q = Radiant energy of the extended source (J)
θ = Angle between the normal to the surface and the direction from which it is viewed (rad)
E_m = MPE for a point-source continuous wave laser (W m^{-2})

H_m = MPE for a point-source pulsed laser (J m^{-2})

$NOHD$ = Nominal Ocular Hazard Distance (m)

30. If the extended-source MPE is exceeded at all distances at which the source can be treated as an extended source, then the NOHD for a lambertian source must be calculated by treating the laser as a point source, as follows:

a. For a continuous wave laser

$$NOHD = \sqrt{\frac{P\cos\theta}{\pi E_m}} \qquad \text{Equation (12)}$$

b. For pulsed lasers

$$NOHD = \sqrt{\frac{Q\cos\theta}{\pi H_m}} \qquad \text{Equation (13)}$$

where

P = Radiant power of the extended source (W)

Q = Radiant energy of the extended source (J)

θ = Angle between the normal to the surface and the direction from which it is viewed (rad)

E_m = MPE for a point-source continuous wave laser (W m^{-2})

H_m = MPE for a point-sourced pulsed laser (J m^{-2})

$NOHD$ = Nominal Ocular Hazard Distance (m)

31. For a *non-lambertian* source, advice should be sought from the MLSC. An example of this type of source is a laser diode array; as, in this case, there is no simple analogue to Inequalities (10) and (11).

32. Beyond R_1, the laser is treated as a point source, and the NOHD is given by Equations (4) or (5).

Example 5

Determine whether the MPE is exceeded for a single pulse from the example laser when it is fitted with the transmitting diffuser and viewed straight on.

The maximum distance at which the diffuse source can be treated as an extended source is (from Equation (3))

$$R_1 = \frac{0.02}{1.5 \times 10^{-3}}$$

$$= \underline{13.3 \text{ m}}$$

The MPE will not be exceeded if the viewing distance, R, satisfies Inequality (11), i.e.

$$R > \frac{0.7 \times 90 \times 10^{-3}}{\pi \times 13.3 \times 5 \times 10^{-2}}$$

which gives $R > 0.03$ m.

Therefore, as R_1 is also greater than 0.03 m, the laser is safe to view at all distances.

Production equipment

33. The beam characteristics of an individual device may vary considerably from the standard specification for that laser type, and manufacturers are advised to make measurements on every laser to establish a worst-case NOHD. Alternatively, the beam divergence, φ, for the uniphase transverse electromagnetic mode (TEM_{00}) of oscillation for that type of laser can be used in Equations (4)–(7), where

$$\varphi = \frac{4\lambda}{\pi d_0 M_0} \times 10^{-9} \qquad \text{Equation (14)}$$

with

λ = Laser wavelength (nm)

d_0 = Diameter of the laser beam, at the 1/e-peak radiant intensity or integrated radiant intensity point, measured at the beam waist (m). A pessimistic approximation for d_0 is 70 per cent of the effective diameter of the laser cavity.

M_0 = Beam expansion factor provided by the system's optics.

34. Note that Equation (14) can only be used for systems in which the optics are in the form of a beam-expanding/beam-folding telescope. For other types of optics, the calculation of beam divergence is more complex and depends on the nature of the optics. If necessary, advice should be sought from the MLSC or the system's manufacturers.

Example 6

Calculate the worst-case NOHD for a single pulse from the example laser if a measured value of beam divergence is not available and the effective laser cavity diameter is 2.5 mm with a ×8 telescope.

From Equation(14):

$$\varphi = \frac{4 \times 1064}{\pi \times 0.7 \times (2.5 \times 10^{-3} \times 8)} \times 10^{-9}$$

$$= 9.7 \times 10^{-5} \text{ rad}$$

$$\text{Worst-case } NOHD = \sqrt{\frac{4 \times 90 \times 10^{-3}}{\pi \times (9.6 \times 10^{-5}) \times 5 \times 10^{-2}}}$$

$$= \underline{15\,770 \text{ m}}$$

This is to be compared with an NOHD of 3028 m obtained using Equation (5), and shows that the example laser has a multimode output.

FACTORS AFFECTING THE NOHD

Ocular Hazard Distance

35. Having calculated the NOHD, it is then necessary to apply a number of corrections to produce a practical hazard distance for use in realistic circumstances. This is known as the Ocular Hazard Distance (OHD) and is the resultant of corrections applied from some or all of the following factors to the NOHD:

a. Viewing through magnifying optics.

b. Beam attenuating filters

c. Laser protective eyewear.

d. Atmospheric scintillation.

e. Near-field effects.

f. Atmospheric attenuation.

36. Each of these factors is considered separately below. When applying more than one factor, it is important to take care over the order in which the correction equations are applied even though *a*., *b*. and *c*. are interchangeable. This is described in the flowchart in Fig. 3A-2, which summaries the procedure to be followed for deriving the OHD, and a fully-worked example is to be found in paragraph 53, page 3A-27. Note that these calculations *must* start with the NOHD as determined from Equation (4) or Equation (5) and not from Equation (6) or Equation (7).

Magnifying optics

37. The effect of viewing laser radiation through magnifying optical instruments is to allow more radiation to be incident on the eye. This will increase the NOHD to a distance called the Extended Ocular Hazard Distance (EOHD), which can be calculated using the following equation:

$$EOHD = NOHD \times \sqrt{K}$$ Equation (15)

where K is dependent on the laser wavelength and the viewing conditions.

Note: In the British Standard, EOHD is known as the *Extended Nominal Ocular Hazard Distance* (ENOHD).

38. For intrabeam or point-source viewing, K is given by the following. (Note that for wavelengths less than 320 nm or greater than 4500 nm, where there is negligible transmission through glass, K is set to 1.)

a. For 320 nm $\leq \lambda <$ 400 nm or 1400 nm $< \lambda \leq$ 4500 nm

$$K = \tau M^2 \qquad \text{Equation (16)}$$

b. For 400 nm $\leq \lambda <$ 1400 nm

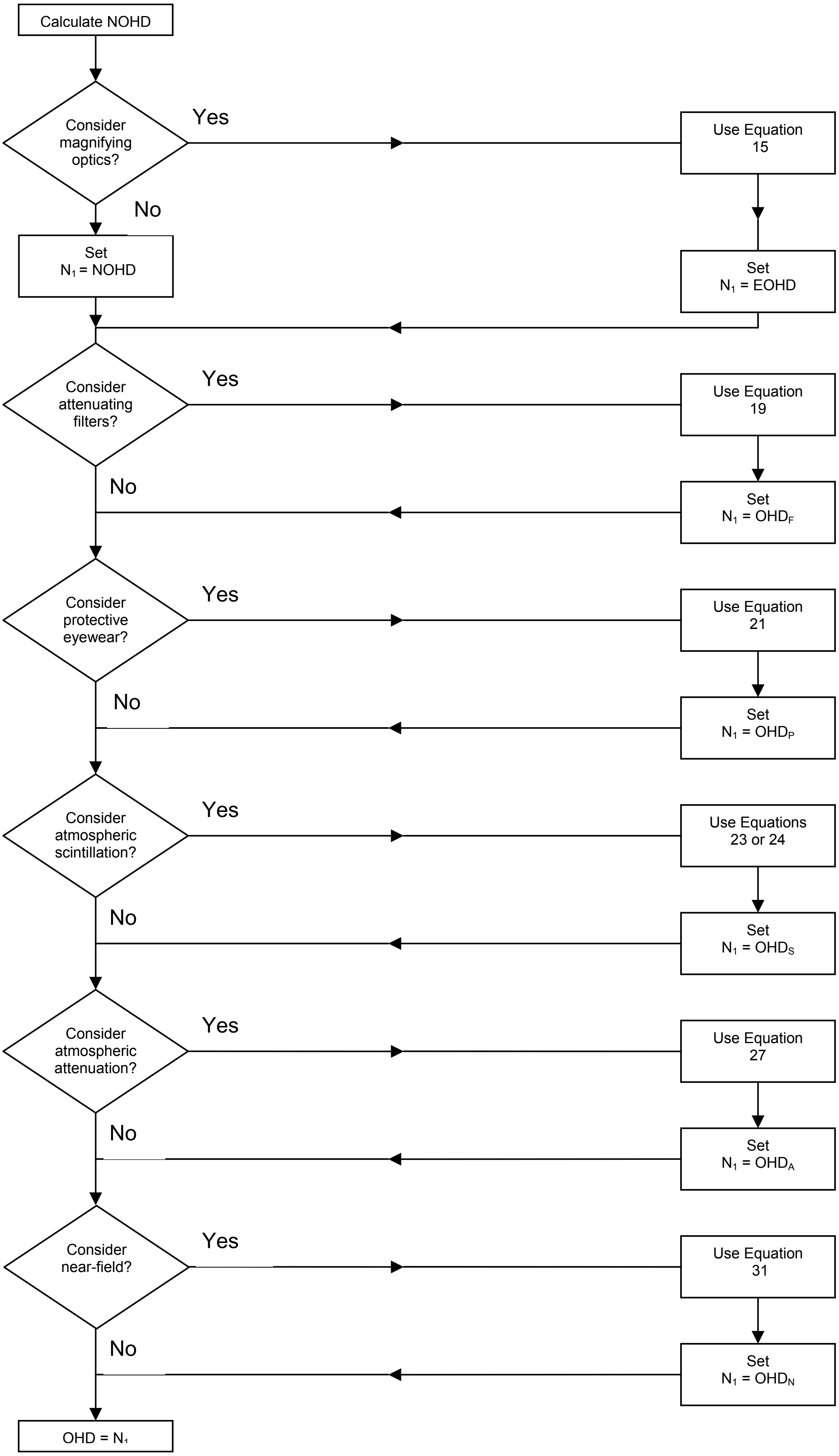
$$\left.\begin{aligned} K &= \tau M^2 \\ K &= \frac{\tau D_0{}^2}{g^2} \end{aligned}\right\} \text{ select lowest value of } K \qquad \text{Equation (17)}$$

c. $\lambda <$ 320 nm or $\lambda >$ 4500 nm

$$K = 1 \qquad \text{Equation (18)}$$

where

λ = Laser wavelength (nm)
M = Magnifying power of the optical system
D_0 = Diameter of the objective lens (m)
τ = Transmittance of the optical system at the laser wavelength
g = Diameter of the pupil of the dark-adapted eye (7×10^{-3} m)


Calculate NOHD
Consider magnifying optics?
Yes
No
Use Equation 15
Set N_1 = EOHD
Set N_1 = NOHD
Consider attenuating filters?
Yes
No
Use Equation 19
Set N_1 = OHD_F
Consider protective eyewear?
Yes
No
Use Equation 21
Set N_1 = OHD_P
Consider atmospheric scintillation?
Yes
No
Use Equations 23 or 24
Set N_1 = OHD_S
Consider atmospheric attenuation?
Yes
No
Use Equation 27
Set N_1 = OHD_A
Consider near-field?
Yes
No
Use Equation 31
Set N_1 = OHD_N
OHD = N_1

Example 7

Calculate EOHD for 10×50 binoculars (having a transmission of 80 per cent) viewing the example laser and ignoring other effects.

Magnification (M) = 10

Transmission (τ) = 80 per cent

$D_0 = 50 \times 10^{-3}$ m

Using Equation (17), choose the lowest value of:

a. $K = \tau M^2$

$= 0.80 \times 10^2$

$= 80$

b. $K = \dfrac{\tau D_0^{\ 2}}{g^2}$

$= \dfrac{0.80 \times (50 \times 10^{-3})^2}{(7 \times 10^{-3})^2}$

$= 40.8$

As the value of K in b. is less than that in a., K = 40.8; and from Equation (15):

Beam attenuating filters

39. Filters are often used in training to reduce the OHD and hence limit the size of the hazard area. To obtain the Ocular Hazard Distance (OHD_F), the following equation is used:

$$OHD_F = N_I \times \sqrt{\tau} \qquad \text{Equation (19)}$$

where

N_I = Either the NOHD or EOHD

τ = Transmittance of the optical system at the laser wavelength

Example 8

Calculate OHD_F for the example laser when it is fitted with a 10 per cent filter, ignoring other *effects.*

If the transmission is 10 percent, then from Equation (19)

$$\begin{aligned} OHD_F &= N_I \times \sqrt{0.10} \\ &= 3028 \times \sqrt{0.10} \\ &= \underline{958\ \mathrm{m}} \end{aligned}$$

Laser protective eyewear

40. Approved laser safety goggles are normally designed to provide protection to the wearer. They are marked with the optical density (OD) number and the wavelength they are designed to attenuate. The OD is defined as follows:

$$OD = \log_{10} \frac{U_0}{U} \qquad \text{Equation (20)}$$

where

U = Laser irradiance (W m^{-2}) or radiant exposure (J m^{-2}) transmitted by the goggles (which should not exceed the MPE)

U_0 = Incident laser irradiance or radiant exposure

41. The Ocular Hazard Distance (OHD_P) which takes into account the use of protective eyewear of optical density OD may be calculated from N_I, using:

$$OHD_P = N_I 10^{-OD/2} \qquad \text{Equation (21)}$$

where

N_I = Either the NOHD or the cumulative OHD_P arising from the full or partial application of factors allowing for magnifying optics and beam attenuating filters

Example 9

Calculate OHD_P for a wearer of goggles marked with OD = 6 when viewing the example laser, ignoring other effects.

The OD number of 6 will reduce the irradiance or radiant exposure by a factor of one million.

$$N_I = NOHD = 3028\ \mathrm{m}$$

Hence, from Equation (21)

$$OHD_P = 3028 \times 10^{-6/2}$$
$$= \underline{3\ \text{m}}$$

Atmospheric effects

42. Turbulence-induced scintillation and attenuation by the atmosphere both affect the transmission of the laser beam through it. The following paragraphs detail how these factors affect the NOHD.

43. *Turbulence-induced scintillation.* It is usual to think of the air in the atmosphere as having a constant refractive index (= 1.0). However, in practice this is seldom true. By day, the radiation from the sun causes the earth's surface to heat and some of this heat is re-radiated back into the air, resulting in a rise in the air temperature close to the earth's surface. This is accompanied by a small but significant change in refractive index. Convection currents and crosswinds break up the air into small regions, each of which can be considered as a weak lens acting to focus or defocus a beam of radiation passing through it. The overall effect is termed *scintillation*.

44. Under conditions when scintillation exists the beam irradiance at the NOHD can exceed the MPE, and therefore it is prudent to make some allowances for this effect. The severity of scintillation is directly related to a quantity C_n, known as the *atmospheric refractive index structure factor*, which has units of $\text{m}^{-1/3}$. Strong turbulence, giving rise to severe scintillation, is likely to be encountered under conditions of strong direct sunlight along beam paths that run parallel to and within a few metres of the ground surface. Medium levels of scintillation may occur by day under cloudy or light overcast conditions, whilst weak turbulence is found at night or under cloudy winter conditions. Weaker levels of turbulence are experienced over the sea which acts as a thermal sink and remains at an almost constant temperature by day and night.

45. Typical values of C_n at one metre altitude over ground and sea are given in Table 3A-4.

Table 3A-4 Typical values of C_n

	Ground ($\text{m}^{-1/3}$)	Sea ($\text{m}^{-1/3}$)
Weak turbulence	1.0×10^{-7}	1.0×10^{-8}
Medium turbulence	$3.0 \times l0^{-7}$	3.0×10^{-8}
Strong turbulence	5.0×10^{-7}	5.0×10^{-8}

For laser safety calculations, the value of C_n, is taken to change with altitude for both over-ground and over-sea paths according to the following power law under all conditions:

$$C_{n_h} = C_{n_1} h^{-2/3}$$

where

C_{n_1} = Value of C_n at one metre altitude ($m^{-1/3}$)
C_{n_h} = Value of C_n at altitude h ($m^{-1/3}$)

46. The following analysis gives a correction to the Ocular Hazard Distance for atmospheric scintillation.

If N_I is less than the parameter $N_{\max}$ where

$$N_{\max} = 2.2 \times 10^{-7} \frac{\lambda^{0.64}}{C_n^{1.09}} \qquad \text{Equation (22)}$$

With λ = wavelength of the laser (nm), then to take account of scintillation, N_I is modified to obtain OHD_S using the following equation:

$$OHD_S = \left(2.66^{N_I / N_{\max}}\right) N_I \qquad \text{Equation (23)}$$

where

N_I = Either the NOHD or the cumulative OHD arising from the full or partial application of factors allowing for magnifying optics, beam attenuating filters and laser protective eyewear

If $N_I \geq N_{max}$, or if it is not possible to determine C_n, then OHD_s is given by:

$$OHD_S = 2.66\, N_I \qquad \text{Equation (24)}$$

Example 10

Calculate OHD_S for a 1064 nm laser rangefinder with an NOHD of 1000 m firing along a horizontal path through an atmosphere for which $C_n = 5 \times 10^{-8}\ m^{-1/3}$.

Using Equation (22), the parameter $N_{\max}$ is therefore:

$$N_{\max} = 2.2 \times 10^{-7} \frac{(1064)^{0.64}}{\left(5 \times 10^{-8}\right)^{1.09}}$$

$$= \underline{1729\ \text{m}}$$

As the NOHD is less than N_{max}, OHD_S is calculated from Equation (23) as follows:

$$OHD_S = (2.66^{1000/1729}) \times 1000$$
$$= \underline{1761\text{ m}}$$

If for the same laser, C_n is not known, then from Equation (24):

$$OHD_S = 2.66 \times 1000$$
$$= \underline{2660\text{ m}}$$

47. *Atmospheric attenuation*. A laser beam passing through the atmosphere is also subject to absorption and scattering by gas molecules, aerosols and dust particles. The degree of attenuation is related to the meteorological visibility, the beam propagation path above the ground and the wavelength of the radiation. The irradiance, E_R, of a non-diverging beam at a range R is expressed as:

$$E_R = E_0 \exp(-\mu R) \qquad \text{Equation (25)}$$

where

E_0 = Emergent beam irradiance at zero range (W m^{-2})
μ = Atmospheric attenuation coefficient, i.e. absorption and scattering (m^{-1})

$$\mu = \left(\frac{3.91}{V}\right) \times \left(\frac{550}{\lambda}\right)^A \text{ m}^{-1} \qquad \text{Equation (26)}$$

48. The general equation for calculating μ for a given visibility and wavelength is as follows:

where

V = Meteorological range (m)
A = $0.06V^{0.33}$
λ = Laser wavelength (nm). In this equation, it is restricted to values between 400 and 2000 nm.

Table 3A-5 gives values for μ for three standard meteorological conditions at various wavelengths.

Table 3A-5 Attenuation coefficient (μ)

Wavelength	μ (m^{-1})		
(nm)	*Medium haze* (5 km)	*Standard clear* (23 km)	*Exceptionally clear* (75 km)
488	8.81×10^{-4}	2.07×10^{-4}	6.98×10^{-5}
514	8.37×10^{-4}	1.90×10^{-4}	6.15×10^{-5}
530	8.11×10^{-4}	1.81×10^{-4}	5.71×10^{-5}
632	6.81×10^{-4}	1.35×10^{-4}	3.72×10^{-5}
694	6.20×10^{-4}	1.16×10^{-4}	2.96×10^{-5}
810	5.31×10^{-4}	8.97×10^{-5}	2.02×10^{-5}
1064	4.05×10^{-4}	5.72×10^{-5}	1.04×10^{-5}
1542	2.80×10^{-4}	3.10×10^{-5}	4.23×10^{-6}

Because the meteorological conditions can change rapidly, any allowance for atmospheric attenuation should be applied with caution.

For practical reasons, it is suggested that where a reliable estimate of V cannot be made μ is taken to be zero, i.e. maximum atmospheric transmission is assumed.

49. The OHD which takes account of atmospheric attenuation, OHD_A, for a laser can be calculated using the following equation:

$$OHD_A = \frac{N_1}{2 - \exp(-0.5\mu N_l)} \qquad \text{Equation (27)}$$

where

N_l = Either the NOHD or the cumulative OHD arising from the full or partial application of factors allowing for magnifying optics, beam attenuating filters, laser protective eyewear, atmospheric scintillation and near-field effects

μ = Attenuation coefficient (m^{-1})

Example 11

Calculate OHD_A the example laser where the meteorological visibility is 5 km, ignoring the effects of scintillation.

V = 5 km

N_l = 3028 m (from Example 9)

λ = 1064 mm

$\mu = \frac{3.91}{5000} \times \left(\frac{550}{1064} \right)^A$ Using Equation (26)

where $A = 0.06 \times 5000^{0.33} = 0.997$

hence $\mu = 4.05 \times 10^{-4}\ \mathrm{m}^{-1}$

From equation (27):

$$OHD_A = \frac{3028}{2 - \exp(-0.5 \times 4.05 \times 10^{-4} \times 3028)}$$

$$= \underline{2077\ \mathrm{m}}$$

Near-field effects

50. The NOHD equations, Equations (4) and (5), are always pessimistic, and can lead to a significant overestimate when the calculated OHD lies in or close to the laser's near-field, which can extend to a considerable distance.

51. The true diameter, d, of a laser beam at range R for a TEM_{00} (gaussian) laser is given by:

$$d = d_0 \left[1 + \left(\frac{2\lambda R \times 10^{-9}}{\pi d_0^{\ 2}} \right)^2 \right]^{1/2} \qquad \text{Equation (28)}$$

where

d = Diameter (m) of the laser beam at range R (with respect to the $^1/e$-peak radiant intensity or integrated radiant intensity).

d_0 = Value of d at zero range (m). Strictly, d_0 is the value at the beam waist, a mathematical quantity which is difficult to measure but a good approximation is to take 70 per cent of the diameter of the laser cavity.

λ = Laser wavelength (nm)

R = Distance (range) from the laser (m)

This equation shows that at short range the beam is essentially parallel, i.e. collimated, of diameter d_0, until the effect of the second term in the expression (the "squared" term) becomes significant. The second term becomes equal to the first term at a range R_N (called the *Rayleigh length*), given by:

$$R_N = \frac{\pi d_0{}^2}{2\lambda} \times 10^9 \qquad \text{Equation (29)}$$

The *far-field* of a laser is that region for which R is much greater then R_N, while the remainder is called the near-field (precise definitions vary according to author).

The laser beam divergence (radians) in the far-field is constant, and is given by:

$$\varphi = \frac{2\lambda}{\pi d_0} \times 10^{-9} \qquad \text{Equation (30)}$$

(The above is generally sufficient for laser systems with or without additional beam-forming optics. If necessary, advice should be sought from the MLSC or from the system's manufacturers.)

52. In these circumstances, for lasers with near-TEM$_{00}$ characteristics, it is possible to calculate a corrected OHD value, OHD_N, which takes into account the effect of the near-field. OHD_N is given by:

$$OHD_N = N_I \sqrt{1 - \left(\frac{R_N}{N_I}\right)^2} \qquad \text{Equation (31)}$$

where

N_I = Either the NOHD or the cumulative OHD arising from the full or partial application of factors allowing for magnifying optics, beam attenuating filters, laser protective eyewear and atmospheric scintillation

R_N = 'near-field' range of the laser, given by Equation (29) or by

$$= \frac{2\lambda}{\pi\varphi^2} \times 10^{-9} \qquad \text{Equation (32)}$$

λ = Laser wavelength (nm)

φ = Laser beam divergence at the 1/*e*-peak irradiance or radiant exposure points (rad)

Example 12

Calculate OHD_N for a 10 s exposure from a 10 Hz Raman-shifted version of the example laser working at 1540 nm, where the output pulse energy has been reduced to 1.3 mJ (ignoring other effects).

The NOHD is calculated using Equation (5):

$$NOHD = \sqrt{\frac{4 \times (1.3 \times 10^{-3})}{\pi \times (0.5 \times 10^{-3})^2 \times 100}} \qquad (\text{MPE} = 100\ \text{J m}^{-2})$$

$$= \underline{8.1\ \text{m}}$$

The near-field range, R_N, is given by Equation (32):

$$R_N = \frac{2 \times 1540}{\pi \times (0.5 \times 10^{-3})^2} \times 10^{-9}$$

$$= \underline{3.9\ \text{m}}$$

If magnifying optics, beam attenuating filters and atmospheric scintillation are ignored, and as

$$OHD_N = 8.1\sqrt{1 - \left(\frac{3.9}{8.1}\right)^2}$$

$$= \underline{7.1\ \text{m}}$$

NOHD = 8.1 m, then from Equation (31):

Note: The value using Equation (7) (the British Standard equation) is 4.2 m.

Summary

53. Fig. 3A-2 illustrates the sequence in which the factors are applied to the NOHD to arrive at the OHD. Paragraphs 35 to 52 explain in detail the individual corrections that need to be applied together with examples. The following example demonstrates the application of some of the factors to the example laser to arrive at a resultant OHD.

Example 13

Calculate the OHD of the example laser fitted with a 10 per cent filter and operating in atmospheric conditions for which the atmospheric refractive index structure factor; C_n, equals $5 \times 10^{-8}\ m^{-1/3}$, and the meteorological range, V, equals 5 km when viewed through 10x50 binoculars.

a. Calculate NOHD. *NOHD = 3028 m* (from Example 4)

b. Consider magnifying optics? *Yes*

c. $EOHD = 3028 \times \sqrt{40.8} = 19341\text{ m}$ (from Example 7)

d. $N_I = EOHD$ =19 341 m (see paragraph 39)

e. Consider attenuating filters? *Yes*

f. $OHD_F = 19341 \times \sqrt{0.10} = 6116\text{ m}$ (from Equation 19)

g. $N_I = OHD_F$ = 6116 m

h. Consider laser protective eyewear? *No*

i. Consider atmospheric scintillation? *Yes*

j. Example 10 gives $N_{\max}$ as 1729 m therefore (from Equation 24)
$OHD_S = 2.66 \times 6116$ = 16 269 m

k. $N_I = OHD_S$ = 16 269 m

l. Consider near-field effects? *No*

m. Consider atmospheric attenuation? *Yes*

n. For a meteorological range of 5 km the absorption coefficient is (from Table 3A-5) $\mu = 4.05 \times 10^{-4}\ m^{-1}$, therefore:

$$OHD_A = \frac{16269}{2 - \exp[-0.5 \times (4.05 \times 10^{-4}) \times 1629]} = 8288\text{ m}$$ (from Equation 27)

o. $OHD = N_I = OHD_A$ = <u>8288 m</u>

REFLECTION HAZARDS

54. When a laser beam strikes an object some of the energy is absorbed whilst the rest is reflected. The ratio of the total amount of energy reflected to the amount incident on the object is defined as the reflection coefficient.

55. The nature of the reflecting surface also affects the size and shape of the laser beam which is reflected. The following paragraphs detail the laser hazards of a laser beam which is reflected from:

a. A specularly-reflecting target.

b. A dry diffusely-reflecting target.

c. A wet target.

Specular reflectors

56. When the angle at which a reflected beam of radiation leaves a surface is the same as the angle at which the incident beam strikes the surface, the reflections are said to be *specular*. Mirrors, both curved and flat, and shiny surfaces such as gloss paint or still water are typical examples of specular reflectors. The reflection coefficient for a specular reflector is dependent upon the nature of the surface, the wavelength, the angle of incidence and the plane of polarization of the laser radiation. Unless detailed analysis of the reflective surface can be determined, a 100 per cent reflection coefficient should be assumed. In this case, the effect of the reflector is solely to deviate the beam. If the angle of incidence is ψ, then the laser beam is reflected in a direction 2ψ from the laser-reflector line (see Fig. 3A-3).

57. The Ocular Hazard Distance from the reflector (OHD_r) along the reflected beam direction is given by:

$$OHD_r = OHD - R \qquad \text{Equation (33)}$$

where

OHD = OHD calculated by applying correction factors to the quantity Z_1 given by the following equations:

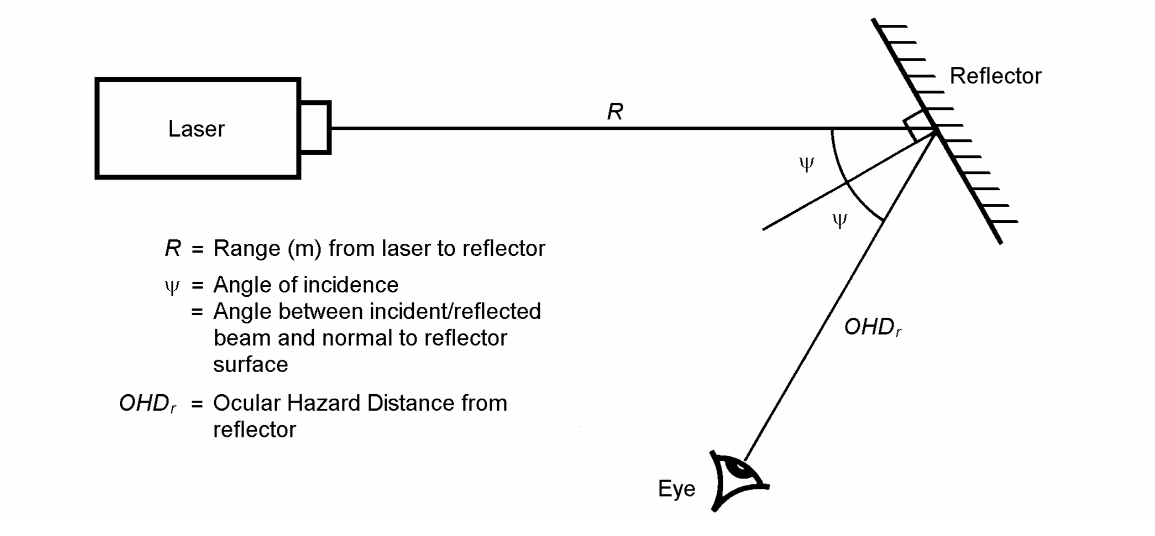


Fig. 3A-3 Specular Reflection

a. For a continuous wave laser

$$Z_1 = \sqrt{\frac{4\rho_S P}{\pi\varphi^2 E_m}} \qquad \text{Equation (34)}$$

b. For a pulsed laser

$$Z_1 = \sqrt{\frac{4\rho_S Q}{\pi\varphi^2 H_m}} \qquad \text{Equation (35)}$$

The correction factors to be applied to Z_1 are identical to those applied to the NOHD in paragraphs 35 to 52, i.e. the OHD may be applied by substituting Z_1 for NOHD in those paragraphs.

ρ_S = Coefficient of specular reflection
P = Radiant power (W)
Q = Radiant energy (J)
φ = Laser beam divergence at the $^1/e$-peak irradiance exposure points (rad)
E_m = MPE for a continuous wave laser (W m^{-2})
H_m = MPE for a pulsed laser (J m^{-2})
R = Distance from the laser to the reflector (m)

If the precise orientations of the reflectors on a target are not known, it is prudent to assume that all orientations are possible, and construct a Specular Reflection Laser Hazard Area Trace (SR LHAT). Such an LHAT applies appropriate OHD_rs to every possible reflected beam direction.

Example 14

Create an SR LHAT for the example laser engaging a target known to have glass surface, e.g. a vehicle with a glass windscreen, at a range of 500 m.

Assuming that factors such as magnifying optics, atmospheric effects, etc., can be ignored, values of OHD are given in Equation (35):

$$OHD = Z_1 = \sqrt{\frac{4 \times \rho_S \times (90 \times 10^{-3})}{\pi \times (0.5 \times 10^{-3})^2 \times (5 \times 10^{-2})}}$$

$$= 3028\sqrt{\rho_S}$$

Hence, from Equation (33),

$$OHD_r = 3028\sqrt{\rho_S} - 500$$

Allowing for multiple internal reflections, the coefficient of specular reflection (ρ_S) from glass surfaces may be obtained from Fig. 3A-4.

Table 3A-6 is generated by using Equation (33) and Fig. 3A-4.

Table 3A-6 Values of OHD_r for typical values of ψ

ψ(°)	ρ_S	OHD_r (m)
0	0.08	356
20	0.09	408
40	0.14	633
60	0.30	1159
70	0.46	1554
80	0.70	2033
85	0.85	2292
90	1.00	2528

From Table 3A-6, it is possible to create the SR LHAT as shown in Fig. 3A-5.

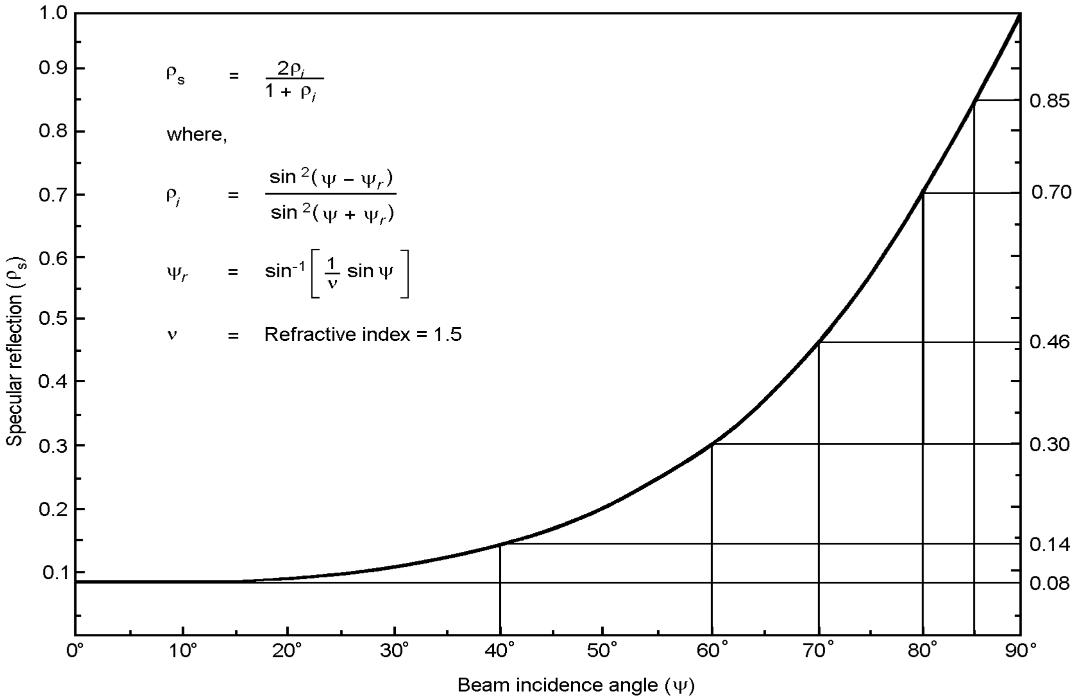


Fig. 3A-4 Coefficient of specular reflection vs beam incidence angle

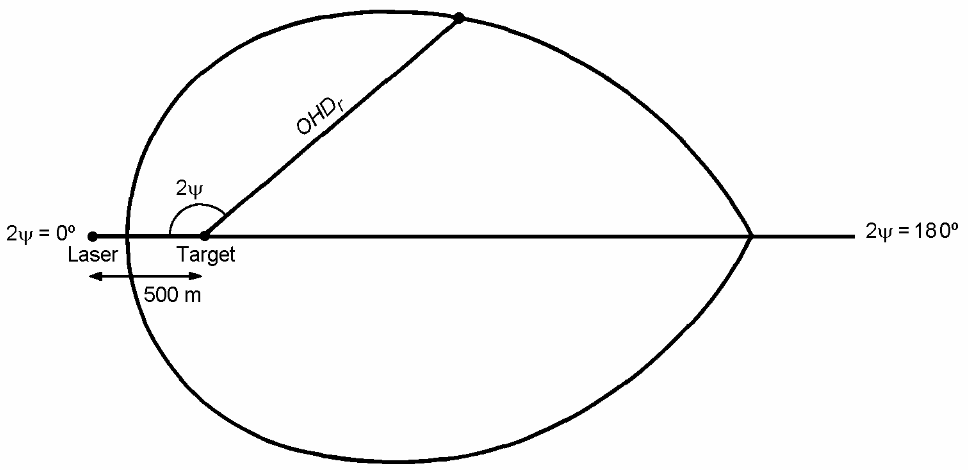


Fig. 3A-5 Typical SR LHAT for the example laser

Dry diffuse reflectors

58. When a laser beam strikes surfaces such as sand, dry earth, dry grass or clothing, the reflected radiation is scattered in all directions – a *diffuse* reflection. The hazards associated with reflection from such 'diffuse' surfaces should be treated by considering the reflecting surface as a diffuse extended source, and assessing the Ocular Hazard Distance from the reflecting surface (OHD_r) using the techniques used in paragraphs 28 and 30.

59. The area, A_R, of the diffuse reflector intercepted by a laser is given by

$$A_R = \frac{\pi(R\varphi)^2}{4\cos\psi} \qquad \text{Equation (36)}$$

where

R = Range of reflecting surface from the laser (m)
φ = Laser beam divergence at the 1/*e*-peak irradiance (rad)
ψ = Laser incidence angle on the reflecting surface (rad)

and point-source viewing conditions will apply when viewing from distances in excess of

$$R_1 = \frac{d}{\alpha_{\min}} \qquad \text{Equation (37)}$$

where $\alpha_{\min}$ is defined in Equation (1) and d is approximated by

$$d = \sqrt{\frac{4A_R}{\pi}} \qquad \text{Equation (38)}$$

60. One of two conditions will apply:

a. If the extended-source MPE is not exceeded, the *OHD*$_r$ from the reflecting surface is zero.

b. If the extended-source MPE is exceeded, *OHD*$_r$ must be calculated using point-source criteria. *OHD*$_r$, is calculated by applying the correction factors in the same way as they are applied to the NOHD, as detailed in paragraphs 35 to 52, to the quantity Z_2 which is given by the following equations:

(1) For a continuous wave laser

$$Z_2 = \sqrt{\frac{\rho_d P \cos\theta}{\pi E_m}} \qquad \text{Equation (39)}$$

(2) For a pulsed laser

$$Z_2 = \sqrt{\frac{\rho_d Q \cos\theta}{\pi H_m}} \qquad \text{Equation (40)}$$

where

ρ_d = Coefficient of diffuse reflection which should be taken as unity unless known
P = Radiant power incident on the reflecting surface (W)
Q = Radiant energy incident on the reflecting surface (J)
θ = Angle between the normal to the diffuse reflector surface and the viewing direction (degrees or radians)
E_m = MPE for a continuous wave laser (W m^{-2})
H_m = MPE for a pulsed laser (J m^{-2})

Example 15

Calculate the OHD$_r$ when perpendicularly viewing a dry diffuse surface having a reflection coefficient of 80 per cent and which is irradiated normally by a single pulse from the example laser.

If *OHD*$_r$ is non-zero, then it will be given by Equation (40), with the single-pulse MPE from Example 1, as follows:

$$OHD_r = Z_2 = \sqrt{\frac{0.8 \times 90 \times 10^{-3} \times \cos\theta}{\pi \times 5 \times 10^{-2}}}$$
$$= 0.7\sqrt{\cos\theta} \ \text{ m}$$

For viewing perpendicular to the surface of the diffuse reflector ($\theta = 0°$),

$$OHD_r = \underline{0.7\ \text{m}}$$

Wet targets

61. Generally, dry military equipment and simulated targets act as diffuse reflectors. However, a target which is coated with a thin film of water may act as a *partial specular reflector.* Because of the random orientation of the reflecting surfaces, it is not always possible to predict the direction of the reflected laser radiation and a hazard area may exist in all directions around the target. Experiment has shown that the worst case 'wet target' is a lightly-rusted flat ferrous metal sheet subject to continual wetting. Under these conditions, the surface should be regarded as a single flat film of water but with the reflected beam gaining a minimum additional divergence of 2.5 mrad.

62. If the angle of incidence is denoted by ψ, the laser beam is reflected in a direction 2ψ from the laser-reflector line (see Fig. 3A-3). The Ocular Hazard Distance from the reflector (OHD_r) along the reflected beam is given by:

$$OHD_r = OHD - R\left(\frac{\varphi}{\varphi + \varphi_1}\right) \qquad \text{Equation (41)}$$

where

OHD = OHD calculated by applying correction factors to the quantity Z_3 given by the following equations:

a. For a continuous wave laser

$$Z_3 = \sqrt{\frac{4\rho_s P}{\pi(\varphi + \varphi_1)^2 E_m}} \qquad \text{Equation (42)}$$

b. For a pulsed laser

$$Z_3 = \sqrt{\frac{4\rho_s Q}{\pi(\varphi + \varphi_1)^2 H_m}} \qquad \text{Equation (43)}$$

The correction factors to be applied to the quantity Z_3 are identical with those applied to the NOHD in paragraphs 35 to 52. All the corrections are applicable with the exception that OHD_S should always be calculated from $OHD_S = 2.66N_1$ (Equation (24), irrespective of the value $N_{\max}$ and the near-field correction should not be applied.

ρ_S = Coefficient of specular reflection (values may be obtained from Fig. 3A-6)

P = Radiant power of the laser source (W)

Q = Radiant energy of the laser source (J)

φ = Laser beam divergence at the 1/*e*-peak irradiance (rad)

φ_1 = Additional laser beam divergence from wet target surface (2.5×10^{-3} rad)

E_m = MPE for a continuous wave laser (W m^{-2})

H_m = MPE for a pulsed laser (J m^{-2})

R = Range from the laser to the target (m)

63. If it is necessary to assume that the laser may be reflected in any possible direction, then a Wet Target Laser Hazard Area Trace (WT LHAT) must be constructed by applying the appropriate OHD_r to every possible reflected beam direction.

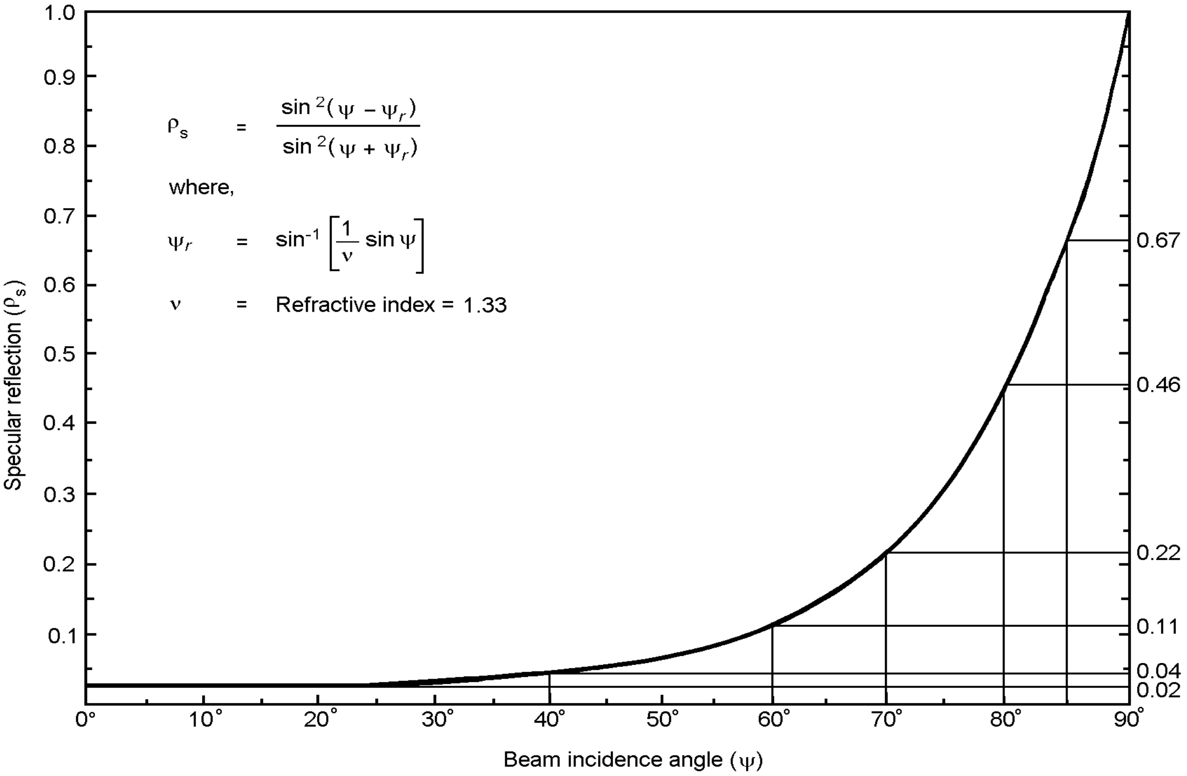


Fig. 3A-6 Coefficient of (wet target) specular reflection vs beam incidence angle

Example 16

Create a WT LHAT for the example laser firing for 10 s at 10 Hz towards a wet target 500 m away.

Assuming those factors such as magnifying optics, atmospheric effects *etc*. can be ignored, values of OHD are given by Equation (43):

$$OHD = Z_3 = \sqrt{\frac{4 \times \rho_S \times (90 \times 10^{-3})}{\pi \times (0.5 \times 10^{-3} + 2.5 \times 10^{-3})^2 \times (5 \times 10^{-2})}}$$

$$= 505\sqrt{\rho_S}$$

Hence, from Equation (41):

$$OHD_r = 505\sqrt{\rho_S} - 500\left(\frac{0.5\times10^{-3}}{0.5\times10^{-3}+2.5\times10^{-3}}\right)$$

$$= 505\sqrt{\rho_S} - 83$$

The reflection coefficients (ρ_S) from the wet target surfaces are obtained from Fig. 3A-6.

From these values, it is possible to create the following table, which gives values of OHD_r for typical values of ψ.

Table 3A-7 Values of OHD_r for typical values of ψ

ψ (°)	ρ_S	OHD_r (m)
0	0.02	0
40	0.04	18
60	0.11	84
70	0.22	154
80	0.46	260
85	0.67	330
90	1.00	422

From Table 3A-7, the WT LHAT can be drawn as shown in Fig. 3A-7.

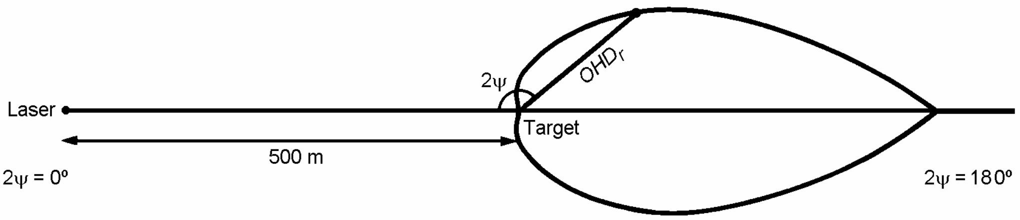


Fig. 3A-7 Typical WT LHAT for the example laser

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CHAPTER 3 ANNEX B

PROBABILISTIC LASER HAZARD ASSESSMENT

GENERAL

1. The NOHD with respect to a controlled area takes no account of the probability of an observer’s eye being irradiated. An alternative method of hazard assessment, which takes such a probability into account and which does not compromise laser safety, is to adopt a probabilistic approach. Situations in which a probabilistic approach is appropriate may be termed *probabilistic laser safety scenarios*, and can be defined as those in which the chance of ocular irradiation is very small, but in which the major elements under consideration are inherently probabilistic.

2. This annex gives ground rules and guidelines to be followed when constructing probabilistic laser safety models, and the principles of judgement used by the MLSC in approving such models. It is important to note that this annex does not give definitive probabilistic laser safety criteria, and is not intended for self-calculation. Probabilistic laser safety scenarios are so widely varying that any treatment of a particular scenario must be individually assessed by the MLSC. A simple illustrative example of an application to an example airborne laser rangefinder (ALR) is used throughout, based on the example laser used in Annex 3A. It will be assumed that the ALR is operated from an aircraft in level flight with zero crosswind, and that:

Total pulse energy (Q) = 90 mJ
Beam divergence (φ) = 0.5 mrad
Wavelength (λ) = 1064 nm
Pulse repetition frequency = 20 Hz
Field of view = ±20° in azimuth;
+10°, –30° in elevation

THE BASIC ELEMENTS OF PROBABILISTIC MODELS

3. In any probabilistic laser safety scenario, the ultimate safety criterion is that the expectation of someone receiving ocular (or skin) damage (E_{OD}) should be less than some ‘acceptable’ risk level (E_{ODMAX}), endorsed by the MLSC.

4. This overall expectation of ocular damage, is obtained by defining probability functions to represent the various probabilistic elements of the scenario, which could lead to a risk of ocular damage; multiplying all of these functions together, and integrating them over all relevant ranges of their associated parameters. The type and number of such probability distributions clearly depends upon the particular scenario, and the degree of analytical complexity being applied.

However, there will always be a basic modelling element which defines the expectation of ocular damage e_{OD} (X) associated with some point X, due to accidental irradiation by a single pulse/burst of laser energy, it should be derived from an equation of the following form:

$$e_{OD}(x) = P_I(X)\int_0^{\infty} P_S(g_S)P_{OD}(g_S H(X))dg_S \qquad \text{Equation (1)}$$

where

$P_I(X)$ = Probability of ocular irradiation of someone situated at point X

$P_S(g_S)$ = Probability density function for the multiplicative gain, g_S, in radiant exposure at point X, due to atmospheric scintillation

g_S = Multiplicative gain in radiant exposure or irradiance due to atmospheric scintillation

$P_{OD}(g_S H(X))$ = Probability of someone receiving ocular damage if irradiated with energy of radiant exposure $g_S H$

$H(X)$ = Level of radiant exposure at point X in the absence of atmospheric scintillation

X = A general point on land, sea or in the air where an unprotected or unwarned person might suffer irradiation by laser energy

(Equation (1) may also be written in terms of irradiance, E, instead of radiant exposure, H, for continuous wave lasers.)

5. Guidelines on the ways in which these probability functions should be defined are given below.

The probability of ocular irradiation, $P_I(X)$

6. Clearly, the function which defines the probability of some point X being accidentally irradiated will be totally specific to the laser safety scenario which is being studied. However, the following general points should be considered when defining the probability of ocular irradiation:

a. The accuracy with which the laser can be pointed under normal operating conditions.

b. The accuracy with which the laser can be pointed in the event of a fault occurring in any part of the laser system which could affect the direction of laser pointing. The associated fault probability should also be considered.

c. The probability of any persons being situated at any point which might be irradiated by laser energy, and the probability of such persons using magnifying optical devices.

d. The probability of any irradiated person looking directly at the laser (or target when considering target reflections).

e. The possibility of an increased probability of irradiation of some point by subsequent laser pulses (or bursts of CW laser energy), if irradiation of the point *X* does occur. If this effect is significant then the basic e_{OD} expectation must be based on the average single pulse expectation of ocular damage for the group of interacting pulses.

f. When considering the hazards from target reflections, the distribution of reflecting surfaces on the target which could cause potentially hazardous reflection.

g. If the laser points outside the Range boundary, it will always irradiate someone *not equipped* with magnifying optics.

h. An irradiated person will *always* look directly at the laser

i. There is no increase in the probability of irradiation of a point *X* by subsequent laser pulses, if irradiation of does occur.

7. In the context of points *a.* to *f.,* a plausible pessimistic representation of the probability of ocular irradiation associated with the use of the example ALR is detailed below.

a. During normal operation, the laser is pointed at the target with angular pointing errors that may be represented by a circular normal distribution, with azimuth and elevation pointing errors having standard deviations, s_E = 5 mrad. Thus, assuming that a point is irradiated with laser energy if it lies within angle φ (laser beam divergence) of the laser boresight, the probability of laser irradiation of a point *X* is:

$$P_{E/FF} = \frac{1}{2\pi s_E^{\,2}} \int_{\alpha_X-\varphi}^{\alpha_X+\varphi} \int_{\varepsilon_X-\varphi}^{\varepsilon_X+\varphi} \exp\left[-\frac{1}{2}\left(\frac{\alpha^2+(\varepsilon_T-\varepsilon)^2}{s_E^{\,2}}\right)\right] d\varepsilon\, d\alpha \qquad \text{Equation (2)}$$

where

α_X and ε_X = Azimuth and elevation angles of point *X* from the aircraft

ε_T = Elevation angle of the target from the aircraft

(The azimuth angle of the target from the aircraft is assumed to be zero, i.e. the aircraft approaches the target on a track passing through the target position.)

b. With respect to operation of the ALR in a fault condition, the only relevant fault conditions are those which cause the laser to fire in directions other than those controlled by the ALR operator. For the ALR it will be assumed that,

(1) Directional control faults occur with a probability, $P_F = 10^{-4}$ per attack.

(2) Laser firing is always inhibited before any pulses can be emitted following a laser

elevation angle control fault.

(3) A single laser pulse can be emitted between the occurrence of an azimuth control fault and the inhibition of laser firing. This pulse can be fired in any azimuth direction within the laser pointing limits, ±A (= ±20°), with *equal* probability.

(4) Laser firing will not recommence after laser firing is inhibited, following a fault condition.

On the basis of the above, the probability of point *X* being irradiated, in the event of a fault condition, $P_{E/F}(X)$ is:

$$P_{E/F}(X) = \frac{P_F}{\sqrt{2\pi s_E{}^2}} \int_{\alpha_X-\varphi}^{\alpha_X+\varphi} \int_{\varepsilon_X-\varphi}^{\varepsilon_X+\varphi} \frac{1}{2\mathrm{A}} \exp\left[-\frac{1}{2}\left(\frac{\alpha^2+(\varepsilon_T-\varepsilon)^2}{s_E{}^2}\right)\right] d\varepsilon\, d\alpha \qquad \text{Equation (3)}$$

8. From the above, it may be seen that the $P_I(X)$ function for the ALR has two distinct parts covering fault-free laser operation ($P_{I/FF} = P_{E/FF}(X)$ from Equation (2)) and laser operation during a laser control system fault ($P_{I/F} = P_{E/F}(X)$ from Equation (3)).

Atmospheric scintillation, $P_S(g_S)$

9. In all outdoor use of lasers, there is a possibility of atmospheric scintillation causing higher than average radiant exposure (or irradiance) levels at any given point, *X*. The multiplicative gain in radiant exposure (or irradiance), g_S, due to scintillation has been found to follow a log-normal probability distribution, with probability density function:

$$P_S(g_S) = \frac{1}{g_S\eta\sqrt{2\pi}} \exp\left[-\frac{\left(\log_e g_S + \frac{1}{2}\eta^2\right)^2}{2\eta^2}\right] \qquad \text{Equation (4)}$$

where

η = Standard deviation of log-irradiance
= The lower of two values $1.11\,[1 - 0.36\exp(-F^2)]\, C_n\,(2\pi/\lambda_1)^{7/12} R^{11/12}$ or 1.1
F = Fresnel number = $\pi a^2/2\lambda_1 R$
λ_1 = Wavelength of laser radiation (m)
a = Diameter of laser aperture (m)
R = Range of laser from the point *X* (m)
C_n = Atmospheric refractive index structure factor. Its value should pessimistically represent the level of atmospheric turbulence likely to exist over the path of the laser beam.

10. As the ALR may be used in conditions in which C_n is not known, η will be taken (pessimistically) to be 1.1.

Ocular damage models, $P_{\mathrm{OD}}(g_S H)$

11. The form of the function defining the probability of ocular damage is clearly dependent upon the actual ocular damage criteria under consideration. Ocular damage criteria should be agreed with the MLSC, but should comply with the following:

a. Ocular damage levels should be small, but still capable of being easily detected, e.g. by ophthalmoscopic inspection.

b. Consequent visual impairment should be minor but not insignificant, so as to allow a meaningful acceptable risk level to be defined.

12. Ocular damage models should always be made pessimistic both for viewing with and without magnifying optical devices, and for the specific characteristics (wavelength, pulse length, etc.) of the laser concerned, e.g. by always assuming that the energy entering the eye is distributed so as to generate the maximum probability of the eye sustaining ocular damage at the chosen level.

13. In certain scenarios, irradiation of a point X by energy from one pulse (or one period of CW laser firing) will imply a higher probability of irradiation of X by subsequent pulses (or periods of CW firing), see paragraphs 6–8. For these scenarios, the ocular damage model must be capable of calculating ocular damage probabilities from multiple pulse (or multiple CW laser firing period) irradiation.

14. A suitable scientific authority (for example the QinetiQ Centre for Human Sciences) always validate any functions used to define the probability of ocular damage.

15. An ocular damage model, defined by the QinetiQ Centre for Human Sciences (formerly the Institute of Aviation Medicine) and endorsed by the MLSC for use in certain probabilistic laser safety scenarios, defines the probability of an eye irradiated with 1064 nm radiation receiving a Minimum Ophthalmoscopically Visible Lesion (MOVL). This is a 30 μm diameter retinal lesion which is just detectable by ophthalmoscopic examination, and, if received on the most sensitive part of the retina, could give minor, but permanent, ocular damage, such as difficulty reading fine print.

16. In the context of this level of ocular damage, P_{OD} is related to the received radiant exposure, $g_S H$, by:

$$P_{\mathrm{OD}}\left(g_S H\right) = \frac{1}{\sqrt{2\pi}} \int_{-1.715 \log_e g_s H + 14.035}^{\infty} \exp\left(-\frac{1}{2} t^2\right) dt$$

17. This function may be combined with the probability density function for atmospheric scintillation defined in paragraph 9, to give an expression for the expectation of an irradiated eye sustaining ocular damage at the MOVL level (E_{MOVL}).

Specifically:

$$E_{\text{MOVL}}(X) = \int_0^\infty P_S(g_S) P_{\text{OD}}(g_S H(X))\, dg_S$$

$$= \int_0^\infty \frac{1}{g_S \eta \sqrt{2\pi}} \exp\left(-\frac{\left(\log_e g_S + \tfrac{1}{2}\eta^2\right)}{2\eta^2} \right) \frac{1}{\sqrt{2\pi}} \int_{-1.715 \log_e g_S H + 14.035}^\infty \exp\left(-\tfrac{1}{2}t^2\right) dt\, dg_S$$

$$= \mathrm{Q}\left[\frac{A\left\{-\log_e H(X) + \tfrac{1}{2}\eta^2\right\} + B}{\sqrt{1 + A^2\eta^2}} \right] \qquad \text{Equation (5)}$$

where A and B here are 1.715 and 14.035, respectively, and $\Theta[x]$ is the complement of the cumulative normal distribution function, $\int_x^\infty e^{-\frac{1}{2}t^2} dt$.

18. Thus the expectation of ocular damage associated with point X, due to accidental irradiation by one pulse from the ALR, is:

$e_{\text{OD/FF}}(X) = P_{E/FF}\, E_{\text{MOVL}}(X)$ for fault-free laser operation, and Equation (6)

$e_{\text{OD/F}}(\text{X}) = P_{E/F}\, E_{\text{MOVL}}(X)$ for laser operation following a directional control fault Equation (7)

The full probabilistic model

19. The full probabilistic model should allow calculation of the overall expectation of someone receiving ocular damage for any particular scenario event, E_{OD}. (A ‘scenario event’ is any single occasion on which the laser is used for its designated purpose.) It is E_{OD} which must be compared with the specified acceptable risk level E_{ODMAX}.

20. E_{OD} is obtained by integrating the elementary expectations, $e_{\text{OD}}(X)$ (from paragraph 4), over all relevant areas of sea, land or air where unprotected/unwarned persons could exist, and summing over all pulses fired (or periods of CW firing) during the scenario event.

21. In the context of the example ALR, a scenario event can be considered to be a laser attack against a single target, e.g. laser firing from four kilometres down to one kilometre range to the target. An appropriate acceptable risk level, E_{ODMAX}, might be such that the laser attack parameters are acceptable, provided that, for any point X, outside the Range boundary:

$$e_{\mathrm{OD/FF}}(X) = \sum_{\text{All pulses fired}} e_{\mathrm{OD/FF}}(X) \leq 10^{-8} \qquad \text{Equation (8)}$$

and $$E_{\mathrm{OD/F}}(X) = \text{maximum over all pulses fired } \{e_{\mathrm{OD/F}}(X)\} \leq 10^{-8} \qquad \text{Equation (9)}$$

(There is no summation in the $E_{\mathrm{OD/F}}(X)$ equation as, at most, only one fault can occur on any single attack.)

Precautions against probabilistic catastrophe

22. When combining probabilistic functions in order to determine the overall expectation of ocular damage for comparison with some acceptable level, great care must be taken. It should always be ensured that if a probabilistic ‘catastrophe’ occurs and either:

a. at least one of the probabilistically-modelled events occurs with unit probability, or

b. at least one of the probabilistically-defined parameters takes some specific value with unit probability,

then the consequent risks of (possibly more serious) ocular damage (E_{CON}) are not unacceptably high. Maximum acceptable levels of this consequent risk (E_{CONMAX}) will always be determined by the level of consequent damage considered. Hence, the appropriate national authority must always determine what level of consequent risk is acceptable.

23. For the ALR, consideration might be given to the consequent risks of receiving a MOVL if an azimuth control system fault *was* to occur so that some person is irradiated with laser energy, *i.e.* the situation in which $P_{E/F} = 1$. If E_{CON} is defined in this manner then, from Equation (7), $E_{\mathrm{CON}}(X) = E_{\mathrm{MOVL}}(X)$. Given that, in reality, $P_{E/F} \leq 10^{-4}$ an appropriate acceptable value of E_{CONMAX} might be 10^{-3}.

Application of the models

24. A laser safety clearance may be given to any set of scenario event parameters if, and only if:

a. the overall expectation of ocular damage, E_{OD}, is less than or equal to the acceptable level, E_{ODMAX}, and

b. the risks of ocular damage in the event of a probabilistic ‘catastrophe’, E_{CON}, are less than or equal to the acceptable level, E_{CONMAX}.

25. One possible way in which conditions *a.* and *b.* above might be satisfied is to define a Laser Hazard Area Trace (LHAT), inside of which all persons should be excluded. For the ALR, firing from a First Laser Firing Point (FLFP) 4 km from the target, down to a Last Laser Firing Point (LLFP) 1 km from the target, at an attack height of 50 m, and an aircraft velocity of 200 m s^{-1},

such a pessimistic LHAT (illustrated in Fig. 3B-1) might comprise:

a. a sector of radius 9.3 km. with apex at the point directly below the FLFP and width ±2° about the aircraft attack track - the Fault-Free Hazard Area Trace (FFHAT) – *and*

b. the area swept out by moving the apex of a sector of radius 1.8 km, and width ±20° from the point directly below the FLFP to the point directly below the LLFP – the Fault Hazard Area Trace (FHAT).

26. It can be shown that, by use of Equations (2), (5) and (6), the FFHAT ensures that $E_{OD/FF} \leq 10^{-8}$ by maintaining that all persons are either beyond a minimum range from the aircraft (which determines the sector length, 9.3 km), or at azimuth angles of more than 2° from the attack track.

27. Similarly, Equations (3), (5) and (7) may be used to show that the $E_{OD/F} \leq 10^{-8}$ and $E_{CON} \leq 10^{-3}$ conditions are satisfied by the FHAT. Essentially, the FHAT covers the possibility of a fault occurring at each point of laser firing and ensures that all persons either cannot be irradiated due to the physical laser pointing limits (± 20°), or can only be irradiated at ranges in excess of 1.8 km from the aircraft.

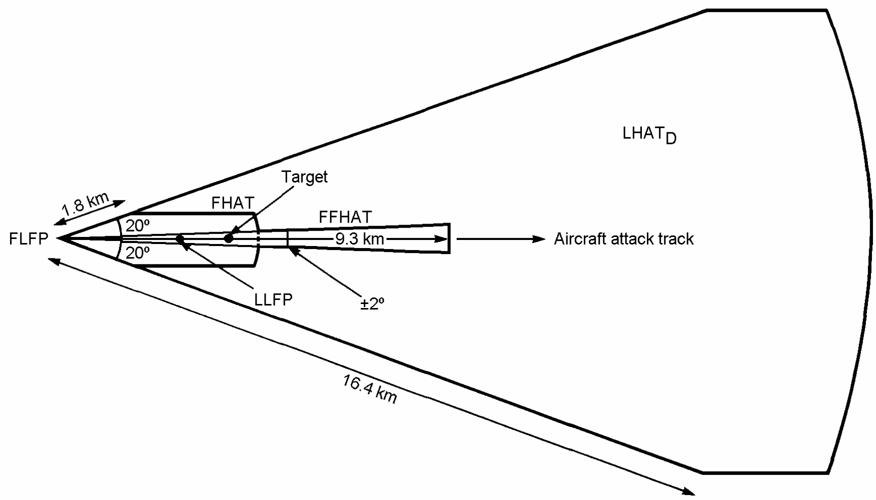

Fig. 3B-1 Probabilistic and deterministic LHATs for the ALR

Comparison of probabilistic and deterministic LHATs

28. Fig. 3B-1 also shows an LHAT constructed using the deterministic hazard assessment techniques described in Annex 3A. This LHAT ($LHAT_D$) applies the OHD which accounts for the effects of multiple pulse irradiation and atmospheric scintillation (16.4 km) over the possible laser azimuth pointing directions (±20°). It is clear that the probabilistic LHAT is significantly smaller that the deterministic equivalent, and would impose less restrictive constraints on the use of the ALR.

GUIDANCE ON ASSESSMENT OF PROBABILISTIC MODELS

29. The following guidelines will be used by the MLSC when assessing probabilistic models and setting probabilistic safety standards.

Probability of ocular irradiation

30. It should be made certain that this has been modelled with adequate pessimism. The level of pessimism required should never be such that it leads to anomalous assumptions (such as assuming that the laser points in all directions simultaneously). Also the modelling assumptions should always generate a probability function which covers the complete ensemble of possible scenario events, rather than individual functions for specific scenario events.

Atmospheric scintillation

31. Values of the atmospheric refractive index structure constant, C_n, should always represent the most severe levels of atmospheric turbulence which could occur over the laser beam path.

Ocular damage models

32. At least one level of possible ocular damage should be considered. It should be capable of being detected practically (e.g. by ophthalmoscopic examination), and cause minor but not insignificant visual impairment, see paragraph 11. All functions for the probability of ocular damage should be pessimistically defined and carry the endorsement of a suitable scientific authority.

Acceptable risk levels

33. The following acceptable risk levels will be defined/endorsed by the MLSC for any given model:

a. E_{ODMAX} (the acceptable overall expectation of someone receiving ocular damage). Its value, when compared with ocular damage expectations (E_{OD}) generated using the full probabilistic model (see paragraphs 19 and 20) determines whether a particular set of scenario event parameters are acceptable. Its numerical value should be set in the context of the level(s) of ocular damage considered and the frequency with which the scenario events occur. Consideration should be given to the complete ensemble of scenario events rather than just individual cases.

b. E_{CONMAX} (the maximum consequent risk of ocular damage in the event of a probabilistic 'catastrophe'). Comparison of E_{CONMAX} with the calculated consequent risk levels, E_{CON}, determines the acceptability of any given set of scenario event parameters. If values of E_{CONMAX} are calculated using the same ocular damage levels as E_{OD}, then E_{CONMAX}

should always be set to be significantly higher than the value assigned to E_{ODMAX} (e.g. E_{CONMAX} might be set at 10^{-1} when $E_{ODMAX} = 10^{-8}$). Clearly, if more serious ocular damage levels are used, then lower values of E_{CONMAX} must be set. The precise value(s) assigned to E_{CONMAX} will depend upon the ocular damage level(s) considered and the number and nature of the probabilistic elements affected by the probabilistic 'catastrophe'. It will also depend upon the frequency with which scenario events occur within the complete ensemble of possible events.

CHAPTER 4

MILITARY LASER SAFETY: RESPONSIBILITIES, QUALIFICATIONS AND TRAINING

Introduction

1. Great importance is attached to the health, safety and welfare of members of HM Forces and of civilians, whether MOD-employed or members of the general public. Detailed health and safety responsibilities are contained in JSP 375. That manual sets out the policy and procedures for implementing the *Health and Safety at Work, etc., Act, 1974* (HSW Act) in the MOD and HM Forces. This chapter draws attention to the applicability of the HSW Act, sets out the military laser safety organization, and prescribes specific areas of responsibilities. It also gives advice on the use of lasers by companies on MOD property, on laser safety training and identifies a suitable training course. The advice contained within this document does not override the requirements given in JSP 418 *Environment Manual.*

Health and safety responsibilities

2. Overall responsibility for health and safety matters within MOD, including laser safety, lies with the Secretary of State for Defence, but his authority is delegated to individual commanding officers and heads of establishments. They are responsible to their superiors in the chain of command or line management for health and safety matters within their units or establishments.

3. The onus of overall responsibility referred to in paragraph 2 does not absolve individuals from the specific responsibilities for health and safety that exist at their command level or level of line management and supervision. In addition, under Section 7 of the HSW Act, all Service and civilian personnel employed within MOD and HM Forces are required while on duty or at work to take reasonable care for the health and safety of themselves and of other persons who may be affected by their acts or omissions.

4. The detailed responsibilities of the line manager under the HSW Act and the method of implementation are included in Chapter 3 Annex B of JSP 375. The guidance contained within JSP 390 covers the responsibilities regarding lasers.

5. Within the MOD, the central co-ordinating branch for all policy questions arising out of the implementation of the HSW Act is DS & C.

Laser safety responsibilities

6. Laser radiation is classed as 'non-ionizing'. The MOD organisations responsible for providing advice on the health and safety of personnel working with lasers are as follows:

a. *Military Laser Safety Committee (MLSC).* The MLSC is an inter-Service advisory committee under the auspices of the Defence Ordnance Safety Board (DOSB), reporting to the Defence Environment Safety Board (DESB). Its function is to set laser safety policy, liase with other MOD and outside organisations, direct the Laser Safety Review Panel and associated working groups, and promulgate best practice to all MOD departments. The MLSC's responsibilities and organisation are detailed in Annex 4A.

b. *Laser Safety Review Panel (LSRP*). The LSRP reports to the MLSC and is composed of subject matter experts from MOD and industry. Its role is to act on requirements set by the MLSC and advise MOD departments on the technical and practical aspects of safety arising from the direct and indirect non-ionizing hazards to people from laser and other optical devices which are in use, or being developed or considered for use, by any of the three Armed Services. This advice maybe in the form of a letter or a Laser Safety Clearance Certificate (LSCC). The LSRP's responsibilities and organisation are detailed in Annex 4A.

c. *Subject Specific Working Groups*. Working Groups are formed by the LSRP to address specific tasks or issues. These could be scientific investigations such as the properties of laser beam parameters or the assessment of a complex laser safety paper. The membership of each working group consists of the most appropriate stakeholders. The working group would exist for the duration of the task and report to the LSRP.

d. *DSTL Radiological Protection Service (DRPS)*. The DRPS provides advice and services to the MLSC in non-ionizing radiological protection, and their primary responsibilities are detailed in JSP 392 *Instructions for Radiological Protection.*

MOD and Service equipment responsibilities

7. *MOD Director Equipment Capability (DEC) sponsor*. The MOD sponsor is responsible for:

a. Writing the staff requirement; in particular, defining the laser requirement including the specification of any general regulations for laser safety.

b. Funding all aspects of laser safety relevant to each equipment.

c. Assisting the MLSC in defining the laser safety aspects during development.

d. Accepting laser-based equipment for single-Service use.

8. *Integrated Project Team (IPT).* The Integrated Project Team managing the production and procurement of equipment employing a laser is responsible for:

a. The concurrent appraisal, within the development contract, of the risks of laser injury to personnel involved in operation, maintenance, inspection and development of equipment, and to any others, e.g. members of the public.

b. The parallel development of laser safety precautions and safety equipment.

c. The incorporation of these laser precautions in equipment manuals and publications.

d. The preparation of the laser training syllabi for operating and maintenance personnel.

e. Ensuring that a Laser Safety Paper (LSP) is prepared and presented to the MLSC for endorsement in accordance with the requirements of Chapter 9.

9. *Customer 2*. Customer 2 controlling and operating laser equipment is responsible for:

a. Ensuring that the laser is operated in a safe manner.

b. Writing laser operational and maintenance orders.

c. Providing personnel with such information, instructions, training and supervision necessary for the safe operation and maintenance of the particular laser equipment, before they start duties associated with that equipment.

d. Based on the information contained in this JSP, the promulgation of laser safety instructions in equipment user handbooks and any other instructions that may be issued from time to time.

e. Ensuring that the medical examination required in Chapter 8 is implemented, where necessary.

f. Seeking MLSC advice on laser safety if any change of use or technical modification is proposed during the service life of the equipment.

g. Safe disposal of the laser, in accordance with Chapter 9 paragraph 12.

Divisional Headquarters and Command Responsibilities

10. *Divisional Headquarters and Commands* are responsible for ensuring that Laser Safety Officers (LSOs) are appointed and that laser safety policy and instructions are covered as necessary in ship, unit, station, establishment, Range and training area orders.

11. *Division and Command Laser Safety Officers*. Division and Command Laser Safety Officers (DLSOs, CLSOs) are to be appointed by the Commander. They are responsible to the Commander for the following aspects of laser safety:

a. Advising the headquarters staff on the preparation of laser safety orders.

b. Supervision and co-ordination of the activities of unit LSOs, affording them all possible assistance in the writing of unit laser safety orders.

c. The approval of all unit laser safety orders, and emergency instructions and procedures.

d. The creation and maintenance of the list of unit LSOs, and forwarding this to the MLSC annually.

e. Ensuring that regular independent inspection of laser protective enclosures, laser equipment maintenance facilities and laser safety equipment is carried out within the Command.

f. The investigation of reports of accidental exposure of personnel to laser radiation and giving advice on corrective action if it is required.

Ship/unit/station establishment responsibilities

12. *Commanding officer / Head of establishment*. Commanding officers (COs) and heads of establishments are responsible for the health and safety of all persons, including the general public, who might be affected as a result of any work carried out at the ship, unit, station or establishment: where this includes laser safety, specific instructions are included in this JSP. They should appoint personnel to assist them in the exercising of these duties. Multiple appointments are permissible provided they do not prejudice safety (e.g. combining the duties of Laser Safety Officer with those of Radiation Safety Officer).

13. *Laser Safety Officer (LSO).* A unit LSO is to be appointed by the CO or head of establishment to co-ordinate laser safety in any ship, unit, station or establishment where lasers are present. The duties of a unit LSO are detailed in Annex 4B.

14. *Range Safety Officer (RSO)*. The RSO should be appointed by the head of the establishment owning the Range. If the Range has a significant laser responsibility, then the RSO should attend the laser safety course at the Defence Academy of the United Kingdom (DAUK), College of Management and Technology (CMT) or the Defence Collage of Aeronautics at Royal Air Force Cranwell (Chapter 4 paragraph 27). The duties of an RSO in respect of laser operations are detailed at Annex 6A.

MOD Agency responsibilities

15. Responsibilities for all safety, including lasers, in MOD Agencies are covered in the MOD Health & Safety handbook. Owing to the nature of the work undertaken at these establishments, e.g. research and trials, it is often necessary to consider individual operations for approval. Overall responsibility for the implementation of safety rests, in the first instance, with the heads of establishments. The head of establishment should consult the MLSC for advice at an early stage, when considering new laser work or facilities. All personnel having tasks concerning the use of lasers must be given training appropriate to their duties. The specific responsibilities for executives whose remit includes laser safety are detailed below.

16. *Establishment Safety Officer (ESO).* The ESO is responsible to the head of establishment for the appointment of Laser Safety Officers (LSOs), and for maintaining a register of lasers, recording the type of laser hazard classification, output wavelength, pulse duration, output energy or power, the lasers' locations, the name of the responsible officers and authorized users (together with the medical surveillance of those personnel, see Chapter 8). He is also responsible for approving and maintaining any local laser safety rules and procedures.

17. *Laser Safety Officer (LSO)*. The LSO, having been appointed by the ESO, is responsible for providing competent technical advice based on this JSP, and other relevant documentation, on all aspects of laser safety. The LSO should be contacted by the establishment, in the first instance, on all questions of laser safety. The duties of an LSO are detailed in Annex 4B.

18. *Divisional safety advisers*. Divisional safety advisers are to ensure that responsible officers have registered their lasers with the ESO, and have also notified the ESO and medical section of the names of the responsible officers and authorized users.

19. *The responsible officer (RO)*. The responsible officer is responsible for the safe operation of a piece of laser equipment. The RO is to register his laser with the ESO and ensure that it is installed in a suitable laser controlled area (if appropriate) with the necessary signs positioned, the necessary protective eyewear available and the appropriate precautions taken. The RO may designate authorized users; however, the RO must then notify the ESO and medical section, and the RO is to ensure that the authorized users are properly trained and aware of any local safety

rules. Personnel who work regularly in or near a laser hazard area are to be treated as if they are authorised users. When appropriate, the RO may prepare local safety rules and submit them to the ESO for approval.

20. *Authorized users*. Only authorized users can operate the laser, taking account of the laser safety advice given by the LSO, suitable training and any local safety rules.

Civilian firms using lasers on MOD Ranges

21. Civilian firms occasionally seek permission to carry out private venture laser trials on MOD Ranges. If the RSO is tasked by the appropriate Service authority to provide facilities or assistance for such work, he should seek the advice of the MLSC. In respect of laser safety liability the following conditions would apply:

22. In general legal terms, primary responsibilities under Sections 2 and 3 of the HSW Act would rest with the civilian firm, with MOD having some secondary responsibility because of its role as the occupier (controlling the premises) under Section 4. The general duty thus placed on MOD requires that all reasonably practicable precautions are taken to protect the health and safety of those who might be affected by activities on the Range. The firm will have a similar duty, with additional specific responsibility for their own employees and those MOD personnel involved in their operations. Beyond these general duties, the MLSC have not identified any special legal requirements.

23. Any civilian firm intending to use an MOD Range must meet the MLSC standards as a prerequisite to such use.

24. The purpose of the MLSC standards and the RSO’s presence at the trial are to ensure, to MOD’s satisfaction, that the trial is conducted safely, according to minimum safety standards. The firm can adopt whatever additional safety arrangements they choose, subject to compliance with MOD safety rules.

Self Certification

25. Individual organisations or establishments involved in trials work maybe permitted to self-certify laser trials at specific sites, with the MLSC acting as the laser safety auditors. To achieve this independence, the organisation concerned must demonstrate to the satisfaction of the MLSC that it has a strong safety management culture and the appropriate technical skills to perform laser safety assessments. The MLSC and the organisation or establishment concerned will produce an agreement document outlining the self-certification procedures and auditing arrangements.

Qualifications and training

26. All Division, Command, unit and establishment LSOs must attend an MLSC approved laser safety course. MLSC-approved LSO courses are held at the Defence Academy of the United Kingdom (DAUK), College of Management and Technology (CMT) at Shrivenham and the Defence Collage of Aeronautics at Royal Air Force Cranwell (see Chapter 4 paragraph 27), or alternatively receive MLSC-approved instruction as part of a career course.

27. *Laser safety course*. The two-day laser safety courses held at the DAUK Shrivenham and RAF Cranwell can accommodate up to 100 students per annum of officer, SNCO and MOD civilian equivalent status. Applications for vacancies should be submitted at least ten weeks in advance through the appropriate Service training officer to:

The Academic Registrar
The Defence Academy of the United Kingdom
College of Management and Technology (CMT)
Shrivenham
SWINDON
Wiltshire
SN6 8LA

Aeromechanical System Training Squadron
Defence College of Aeronautical Engineering
RAF College Cranwell
Sleaford
Lincolnshire
NG34 8HB

28. *Laser operators.* All personnel responsible for the firing of a laser are to receive appropriate laser safety training. When given during a particular weapon or equipment training course, the training is to be co-ordinated by the single-Service sponsoring the introduction of the equipment. The documentation for the introduction into service of any laser equipment should include the procedures for training the user. Such procedures must be in place before MLSC approval is given.

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CHAPTER 4 ANNEX A

MILITARY LASER SAFETY COMMITTEE

Terms of Reference

a. Be the MOD focus for laser safety.

b. Report to the DOSB

c. Direct the activities of the Laser Safety Review Panel (LSRP) and associated working groups.

d. Provide policy and other necessary direction for the safe use of lasers by the services and other MOD organisations and agencies.

e. Review and co-ordinate where necessary all matters regarding laser safety which affect MOD Personnel and visiting forces.

f. Identify the levels of hazard and degree of risk involved in the use of lasers and other optical devices, and on the precautions to be taken against possible injury from them.

g. Sponsor and oversee the production of Joint Staff Publications (particularly JSP 390 *Military Laser Safety*), forms and other documents, which provide (mandatory) instructions guidance for all concerned in the use of laser systems on MOD Ranges or used by MOD personnel.

h. Act as custodian of STANAG 3606.

i. Maintain awareness of, and advise on current developments in national and international laser standards.

j. Nominate delegates to NATO committees and other international agencies where laser safety is addressed.

Composition of the MLSC

Chairman	DOSGTS_AD (Technical Services Assistant Director, Defence Ordnance Safety Group)
Secretary	DOSGTS3i
Members	DOSGTS3i1
	Representatives from DLRSC
	Representative from DS & C
	Representative from DSTL
	Representative from DTEG
	Representatives from HQ Land
	Representatives from HQ STC
	Representatives from C-in-C Fleet
	Representatives from Customer 1 stakeholders
	Representatives from other safety bodies as required
	Representatives from industry (where appropriate)

LASER SAFETY REVIEW PANEL

Terms of Reference

a. Report activities to the MLSC (and other safety bodies as required).

b. Promulgate policy and other necessary direction for the safe use of lasers and other optical devices by the services and other MOD organisations.

c. Identify the levels of hazard and degree of risk involved in the use of lasers and other optical devices, and on the precautions to be taken against possible injury from them.

d. Provide advice on the safety of lasers and other optical devices at the request of MOD departments, agencies or other appropriate bodies by reviewing Laser Safety Papers, assessing and approving Laser Safety Models using Probabilistic Risk Analysis. Issuing appropriate documentation including advice letters or Laser Safety Clearance Certificates (LSCCs).

e. Sponsor and support laser safety training throughout MoD.

f. Review, update and maintain JSP 390 and STANAG 3606 (in liaison with other international bodies) and other documentation on behalf of the MLSC.

g. Maintain liaison with other Services laser agencies in the UK and in other countries.

Composition of the LSRP

Chairman	DOSGTS3i
Secretary	DOSGTS3i1
Laser safety experts	Representative from DSTL Representative from QinetiQ Representative from BAE Systems
Members	Representatives from industry as required Representatives from Customer 1 stakeholders as required Representatives from Customer 2 stakeholders as required Representatives from other safety bodies as required

SUBJECT SPECIFIC WORKING GROUPS

Terms of Reference

1. To resolve the specific task to the satisfaction of the LSRP.

Composition

2. Working Groups would be formed by the LSRP to address specific tasks or issues. These could be scientific investigations such as laser beam properties or the assessment of a laser safety paper.

3. The working group would exist for the duration of the task. The chairman of each working group would be appointed by the LSRP. The chairman of the working group would be the most appropriate person for the role whether this might be the LSP representative, the IPT project manager, Customer 2 or Contractor. In cases where MLSC responsibilities overlap with other functional safety bodies then representatives of both organisations will be represented on the working group. The chairman reports to the LSRP (and other safety bodies if required).

Organisation

1. The MLSC sets policy and reports to the Defence Ordnance Safety Board (DOSB), supported by the LSRP and *ad hoc* working groups as required

2. The LSRP works in conjunction with other safety bodies such as the Ordnance Safety Review Panel (OSRP) and the Defence Land Range Safety Committee (DLRSC) in setting guidance and policy for weapon and range safety issues. In cases where lasers are embedded or clearly aligned with Ordnance Munitions and Explosives (OME) systems, laser clearance requirements will be flagged as part of the ORSP, as shown in Fig. 4A-1. The review of such systems may require members of the MLSC attending the OSRP. If the laser system is a stand-alone item not relating to and OME systems will be cleared directly by the LSRP or by the working group formed that purpose.

3. LSRP membership consists of a permanent Chairman and Secretary with laser safety technical specialists and co-opted representatives from Customer 1 and 2 as required. The LSRP would also have responsibility for maintaining JSP 390 and for providing input to reviews of STANAG 3606. The LSRP would provide a focus for the following tasks; research and modelling via contract support, laser safety advice through LSCC, review of laser safety papers, maintaining JSP 390 and support to reviews of STANAG 3606.

4. The LSRP is supported by individual working groups convened to address specific issues. The nature of some tasks such as PRA modelling, high power system requirements and documentation may require that a working group could be constituted on a more permanent basis. Each working group would report to the LSRP on progress with the precise size and makeup of the membership depending on the nature of the task. For larger systems, or more technical applications, the working group could include a member of the LSRP to provide technical advice, the IPT project manager, or representatives of Customer 1 / Customer 2, QinetiQ or DSTL as appropriate. In cases where there is a functional overlap between safety bodies members of both safety organisations can be represented if required, the working group will report to both safety bodies.

Work of the MLSC organisation

1. The MLSC works in response to requests from MOD departments for advice and laser safety clearances, and to self-generated proposals:

   a. Requests from MOD departments for advice shall be sent initially to the LSRP (see Annex 9A). If the task merits the formation of a working group the Chairman of the LSRP will agree the membership and Terms Of Reference (TORs) with the duty holder.

b. Following the initial guidance from the LSRP or working group the duty holder should submit a Laser Safety Paper (LSP) giving full technical details of the laser system concerned.

c. The LSRP or working group studies the LSP and provides advice to the duty holder. The chairman signs and issues the LSCC, and subsequently reports to the appropriate superior authority.

d. In the areas of self-generated proposals, the LSRP or working groups complete the task and report to their superior authority.

e. The MLSC reports annually to the DOSB.

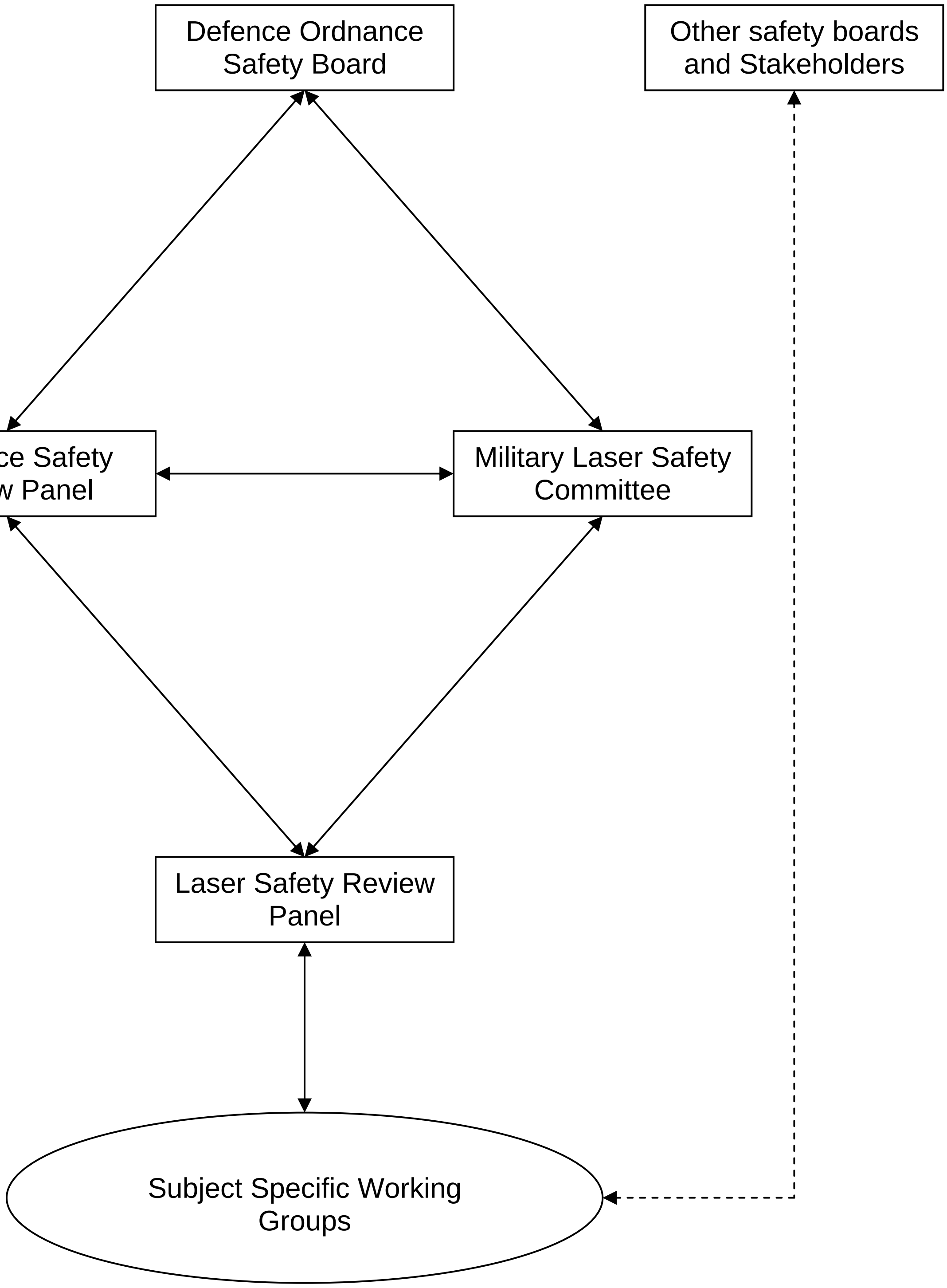

Fig. 4A-1 The Military Laser Safety Committee organisation and reporting chain

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CHAPTER 4 ANNEX B

RESPONSIBILITIES OF A LASER SAFETY OFFICER

1. The responsibilities of a unit/establishment Laser Safety Officer (LSO) will be laid down by the CO or head of establishment and will normally include the following:

General responsibilities

2. An LSO is responsible for:

   a. Providing the CO or head of establishment with advice on laser safety matters.

   b. The preparation and publication of laser safety standing orders and operating procedures.

   c. Ensuring that the relevant laser safety standing orders and operating procedures, applicable to each laser equipment, are correctly applied when the equipment is in store, undergoing maintenance/repair or is in use.

   d. Ensuring that frequent inspections of laser protective enclosures, laser equipment operations, and laser protective eyewear and clothing are carried out and recorded.

   e. Maintaining an up-to-date record on each laser worker required to work regularly in a Laser Hazard Area (LHA) and passing the information on to the relevant medical authority in accordance with Chapter 8 paragraph 4.

   f. Ensuring that the name of the LSO and a list of authorized laser users is prominently displayed within each laser work area.

   g. The immediate reporting and investigation of any possible/suspected overexposure to laser radiation in accordance with Annex 8A, and ensuring that the individual concerned is referred at once to a qualified ophthalmologist.

Laser laboratories and maintenance units

3. In laser laboratories and maintenance units, the LSO would also be responsible for:

   a. Ensuring that strict laser key control and system safety equipment integrity for each Class 3B and Class 4 laser system is maintained each working day.

   b. Ensuring that protective enclosures are provided for each laser product installation and the laser beam is fully enclosed.

c. Where this is not possible, ensuring that beam attenuators or beamstops are used and are carefully maintained.

d. Advising on the prevention of unintentional specular reflections within the laboratory/maintenance area.

e. Ensuring that the approved type of protective eyewear is available and serviceable for use with Class 3B and Class 4 laser products.

f. Ensuring that protective laser clothing is provided for Class 4 CW infrared laser system laboratory maintenance personnel.

g. Ensuring that correct laser warning signs, as detailed in the British Standard, are used with each laser system.

CHAPTER 5

LASER SAFETY PROCEDURES DURING LABORATORY AND WORKSHOP OPERATIONS

Introduction

1. This chapter describes the principles of laser safety employed during both laser laboratory and laser workshop (maintenance) operations. Indoor laser lecture aids (laser pointers/pens) and laser displays are to be regarded as military lasers and treated accordingly.

Laboratory and workshop safety principles

2. The principles for laser safety depend on:

   a. The hazard classification of the laser.

   b. The environment where the laser is used.

   c. The personnel within the vicinity of the laser beam.

The control measures are primarily dependent on the laser classification. Consideration of the environment plays only a minor role. A Laser Safety Paper shall be produced and a Laser Safety Clearance Certificate obtained for all laser operations, e.g. for the workshop as a whole (see Chapter 9 paragraph 6 et seq.)

3. *Enclosed lasers.* The control measures required for Class 1 and Class 2 laser systems are minimal. It is the use and application of Class 1M, Class 2M, Class 3R, Class 3B and Class 4 lasers that require careful study of the hazards and the development of detailed control measures. Total enclosure of any laser source, which is light-tight, with safety interlocks would result in a Class 1 laser system. Specific enclosures may need to be developed for some applications. Moreover, the use of an enclosure is strongly recommended.

4. *Lasers not enclosed*. Where a Class 1M, Class 2M, Class 3R, Class 3B or Class 4 laser beam is not enclosed, either indoors or outdoors, the unit LSO must consider the need to implement the control measures detailed in this chapter. The extent of the control measures within the operating area depends on several factors, including the existence of interlocks.

General control measures for indoor operations

5. Most control measures fall into the category of common sense and good working practice, aimed at limiting the laser exposure and thus reducing the risk of injury to personnel. Control measures may, however, be broken down into four groups:

a. Engineering controls (e.g. enclosures, interlocks and beamstops).

b. Administrative controls (e.g. signs, warning lights, bells, whistles, safe operation procedures and key control).

c. Personal protection (e.g. eyewear, gloves and protective clothing).

d. Training.

These are summarized in Table 5 -1.

Table 5-1 Protection requirements

Subject	Class 1	Class 2	Class 1M	Class 2M	Class 3R	Class 3B	Class 4
Remote interlock	Not required	→				Connect to room or door circuits	
Key Control	Not required	→				Remove key when laser not in use	
Beam attenuator	Not required	→				When in use prevents inadvertent exposure	
Emission indicator	Not required	→				Indication required when laser is energized	
Warning Signs	Not required	→				Entrances posted with appropriate warning signs	
Beam termination	Not required	Terminate at end of useful path			→		
Specular reflection	No special precautions		Care with surfaces that could focus the beam		Prevent unintentional specular reflection		
Optically-aided viewing	No special precautions		Care with optically aided viewing			Do not viewing beam with or without optical aids	
Eye protection	Not required	→			Required where engineering and administrative controls are not practicable		
Protective clothing	No special precautions	→					Specific recommendat-ions
Training	No special recommendations		→		Required for all operating and maintenance personnel		

6. Engineering controls generally entail placing the laser within a protective enclosure, as is done with most industrial lasers used today. In some applications, it is possible to reduce the laser output irradiance below exposure limits without detriment to the system operational performance. Such a practice may become more widespread as advances in detector sensitivity make lower beam power adequate. This is particularly true of the less-hazardous far-infrared wavelengths which are now limited by detector technology. Door interlocks and beamstops are other examples of engineering controls.

7. Environmental controls differ widely, depending upon whether the laser is used in an indoor or outdoor environment. Backstops and shields to exclude the beam from occupied areas are commonly used both indoors and outdoors. Well-illuminated laboratories and limited-access rooms are also important environmental controls. The prevention of unsafe acts by personnel may be achieved by the use of physical barriers and/or by the application of site controls, procedures, training and education, and through careful supervision.

8. Control measures that apply directly to the potentially-exposed individual are the use of standard operating procedures and the use of protective eyewear and clothing. Protective eyewear is a major control that is mandatory when there is any risk of exposure of the eye to hazardous levels; unless this is impractical, when other more-appropriate control measures must be taken and approved by the LSO. However, such situations should be minimized by the use of other control measures where possible.

General safety precautions

9. *Safety precautions.* Safety precautions must be taken to protect personnel using lasers and also any other personnel who might otherwise be accidentally exposed to hazardous laser radiation. Where reasonably practicable, any laser installation should be enclosed and interlocked to prevent access to radiation levels in excess of the MPE (i.e. built into a Class 1 housing). Where this is impractical, the appropriate precautions are determined by laser hazard classification and are given in the British Standard. The precautions detailed in the following paragraphs serve to supplement those given in the British Standard which are mandatory.

10. *Safety precautions for Class 3B and Class 4 lasers.* The following safety precautions should be taken when using Class 3B and Class 4 lasers:

a. They should be installed so that there is no hazard outside the controlled area.

b. Access to the controlled area is to be interlocked or some other effective means of control should be used to prevent unauthorized access. Any equipment interlock should switch off the laser, or reduce the output energy to a safe level, and should be failsafe. The efficiency of any interlock system must be tested periodically (e.g. daily).

c. The standard warning signs, indicating the laser hazard (including the laser wavelength), must be visible prior to entry to the hazard area. Illuminated signs are recommended and, where used, they should be illuminated automatically whenever the laser is operating. British Standard signs should be obtainable through the unit LSO.

11. *Safety precautions for Class 3B and Class 4 lasers in research laboratories*. The following alternative precautions may be applied in exceptional circumstances subject to the approval of the unit establishment LSO:

a. In many cases, a laser power supply will have terminals specifically intended for connection to an interlock, and the use of interlocked access is straightforward. However, in some cases, there may be technical difficulties in connecting an interlock, in which case it may be possible to install a laser so that risk or eye injury to unauthorized personnel is effectively eliminated without recourse to interlocks.

b. Interlocks for Class 3B lasers are recommended, but are not essential providing the following points are followed:

(1) The laser should be installed in a room so that the beam cannot shine through any open door or window.

(2) The laser beam shall be directed away from access points, thereby ensuring that any person entering the laboratory does not immediately enter the beam.

(3) The laser should not be left running unattended if there is a risk of unauthorized personnel entering the laboratory and being injured by the beam. Laboratory doors may be locked to prevent access to an unattended laser.

c. Automatic shutters may be used to provide safety protection without switching the laser off (in some cases, lasers may take more than an hour to stabilize and may suffer a reduction in their operating life by frequent switching on and off). Use of ‘override’ switches may be allowed with Class 4 lasers emitting visible beams so that authorized researchers can enter and leave a laboratory without disturbing experiments.

d. Illuminated signs are not necessary if all the lasers in a laboratory are interlocked, although they may be used to discourage unwanted interruption. Signs are essential if there is a Class 3B or Class 4 laser in a laboratory which is not interlocked.

12. *Good indoor working practices for Class 3B and Class 4 lasers.* The following measures are good working practice and are to be adopted where practicable in the interests of safety:

a. Work with lasers is to be carried out in well-lit areas. This restricts the size of the pupil and so limits the amount of energy that may inadvertently enter the eye. Walls should be painted in a light-coloured matt finish.

b. The beam is to be terminated at the end of its useful path with a beamstop or beam dump.

c. Unintentional reflections (e.g. off windows, polished metal, watches, jewellery, gloss paint and pools of water) must be avoided.

d. Windows should be permanently boarded with fireproof material. Curtains and blinds are not adequate.

e. The laser beam should be well-above or well-below eye level.

f. There should be a laser emission indicator which should be audible or visible to the operator through any protective eyewear and should warn personnel when the laser is operating.

g. There is to be effective control of laser keys to prevent unauthorized use.

h. Beams should be enclosed within a suitable housing; for example, plastic plumbing tube.

i. Access to the controlled area is to be interlocked. If interlocking is impractical for any reason, authorization to operate the laser must first be obtained from the unit LSO.

j. Illuminated warning lights should be used at all access points, indicating automatically whether or not it is safe to enter the room.

k. Local safety rules, approved by the unit LSO, are to be issued to all authorized users and displayed in the hazard area.

l. Readily identifiable and accessible ‘emergency isolation’ switches should be provided, and these should be tested periodically (e.g. daily).

m. The correct protective eyewear must be available. The choice of eyewear must depend on the wavelength and intensity of the laser energy (see Chapter 7).

n. The operator must ensure that everyone in the controlled area is using suitable protective eyewear prior to giving a countdown to laser firing.

o. Lasers in any particular location should have the same wavelength.

p. If using lasers with more than one wavelength then the protective eyewear must be appropriate to all the wavelengths emitted by the laser(s) and carefully marked.

q. Personnel without complete and effective eye protection must avoid viewing beams displayed on diffusing beamstops.

r. Protective clothing must be available and worn where appropriate.

s. Adequate ventilation, or use of a suitable extraction system, must be provided when using a Class 4 laser because of the possibility of some materials (e.g. Perspex) giving off toxic fumes.

t. As some Class 4 laser beams are capable of starting fires, procedures are to be adopted to minimize this risk and suitable fire-fighting equipment is to be readily available.

u. When using battery-operated laser devices within a laser-firing enclosure, batteries should not be fitted except at the time the device is required to be operated.

v. The efficiency of the electrical earth and the connections to it must be checked.

w. Any charge in the energy storage capacitors (if used) must be dumped to earth prior to working on the laser in any way, and after laser firing/testing is complete.

x. Lasers should only be tested when fitted to the appropriate test equipment, or when a suitable beamstop and safety equipment is in place.

1st line laser maintenance safety procedures

13. To achieve safe operation of a laser at unit 1st line level, the following precautions must be taken:

a. The operator must be fully conversant with the laser he is authorized to use, and be approved to use the device. The laser must not be fired without prior authority from the LSO or other responsible person acting on his behalf.

b. The operator must fully understand the warnings, hazards and safety precautions associated with the laser equipment he is operating, servicing and/or maintaining.

c. All personnel who regularly work in laser hazard areas should have their eyes examined regularly as detailed in Chapter 8 paragraph 5.

d. Where a key is provided to lock and make safe the laser and or its associated power supply unit, the possession of the key must be restricted to authorized personnel involved in the actual operating, servicing or maintenance of the equipment. The following points should be noted:

(1) When not in use, the key must be held by a responsible person such as the workshop officer, the unit LSO, or the laboratory supervisor.

(2) The key must not be left in unattended equipment.

(3) The laser and/or its associated power supply unit must be locked or kept in a secure place at all times except for firing or repair of the equipment.

(4) A register must be kept of personnel authorized to operate the equipment.

e. Class 1M, Class 2M, Class 3R, Class 3B and Class 4 lasers must be treated as loaded weapons for safety reasons when connected to their power source.

f. When Class 1M, Class 2M, Class 3R, Class 3B and Class 4 lasers are not operated in a light-tight enclosure, the operator’s eyes must be protected at all times when the laser is in use either by the wearing of the correct type of laser protective eyewear or by using any filter provided with the equipment.

g. The laser beam must not be aligned with the eye.

h. Reflections of a laser beam from a specular surface must be considered to be as hazardous as the main beam. For this reason all unnecessary shiny surfaces must be removed from the laser hazard area, sprayed with matt black paint, or covered up to prevent specular reflections.

i. The room should be well-illuminated.

j. Unnecessary exposure of the skin to laser beams must be avoided.

k. Since pulsed laser systems can store a very high voltage charge, caution must be exercised to avoid accidental pulsing of the laser and the possibility of a lethal electric shock.

l. A nonreflective and fire-resistant background (such as a matt, brick surface) should be used to terminate the beam (a beamstop). Flammable materials, such as paints or cleaning fluids, must not be stored in the laser hazard area.

m. An open-Range target is not to be used where approved test equipment is provided. In the absence of approved test equipment or an authorized open Range, lasers should only be fired in an approved laser protective enclosure, which, at unit level, could be a closed hangar or a repair vehicle. When an approved enclosure is not available or practicable, laser firing falls into two broad categories:

(1) *Protected firing*. A protected laser firing is one in which the laser beam is wholly contained and terminated by a mechanical device or beamstop.

(2) *Unprotected firing*. An unprotected laser firing is one in which the laser beam traverses free space before being terminated by a mechanical device, e.g. harmonization board or other suitable beamstop.

Protected firing does not require the physical presence of an LSO, but only approved procedures and equipment are to be used. In exceptional circumstances, unprotected firing may be undertaken, but requires the presence of an LSO at each firing in addition to LSO approval of the procedures and equipment.

n. Any accident, including burns to the skin, must be reported immediately to the unit LSO and the individual referred at once to the unit medical officer. Subsequent actions are detailed in Chapter 8 paragraphs 8 and 9**.**

2nd and 3rd line laser maintenance safety procedures

14. In both 2nd and 3rd line maintenance workshops, lasers should be repaired, tested and adjusted in laser protective enclosures.

15. In addition to the safety precautions detailed in paragraph 13, the following precautions are to be observed where reasonably practicable at both 2nd and 3rd line:

a. Laser warning signs, as detailed in the British Standard, must be prominently displayed on the outside of each door giving access to the enclosure.

b. A steady red warning lamp must be provided above each entry door to indicate when laser firing is in progress.

c. A prohibition sign '**No entry when red light is on**' must be prominently displayed on each entry door to the laser protective enclosure. Personnel who are not involved in laser work must not enter or attempt to enter a laser protective enclosure without first obtaining permission to do so.

d. Each door, whether it is an entry or exit door, must be fitted with an interlock switch that automatically switches off the supply to the laser power supply or closes a shutter to terminate the beam whenever the door is open. On closing the door, the supply to the laser should not be automatically switched on or the shutters removed until a mechanical reset switch on the power supply unit is reset by hand. The interlock and warning lamp system is to be checked daily.

e. Appropriate laser protective eyewear must be used by all personnel within the laser protective enclosure. Protective eyewear must be regularly checked for defects.

f. Laser beam paths are to be directed above or below eye level, or be terminated by a beamstop.

g. Beam paths are to be enclosed.

h. All laser equipment is to be accurately and securely attached to the test bench to ensure correct orientation of the beam before firing.

i. The target area should be painted matt black (nonreflective). The firing area should be isolated from the repair section of the laser protective enclosure by a permanent rigid structure, such as partitioning walls.

j. All windows in the laser protective enclosure must be blacked out before and during any laser firing. A particularly good way of achieving this is to provide sliding covers for all windows incorporating interlock switches that automatically switch off the laser power supply if a window is not completely obscured.

k. If appropriate for the class of laser, a local sign, e.g. **'Lasers must not be fired until all persons present are wearing goggles and a responsible person is in attendance'** is to be prominently displayed adjacent to the pedestal supporting the laser being fired.

l. All warning lamps and any test equipment read-outs within the laser protective enclosure, unless not required during laser firing, must be of such a colour that they are clearly perceivable through the laser protective eyewear specifically designed for the wavelength(s) of the emitted laser radiation.

m. The major assemblies of a laser system must be earthed adequately at all times in order to protect the user from electrical shock.

n. A fire extinguisher is to be provided immediately outside each entrance door. It shall be of the appropriate type and capacity as recommended by the fire officer.

16. *Workshop practice in the field.* When an approved laser protective enclosure is not available, alternative precautions are necessary to safeguard the maintenance staff and other persons. In the field, an enclosure could be the load compartment of a vehicle, or a suitable backstop, that has been prepared to prevent the escape of hazardous laser emissions or reflections. Where there is no lockable door, entry into the hazard area is to be controlled by a sentry. Where doubt exists on the hazard level in such an area, advice should be sought from the unit LSO. Occasionally, a distant target is desirable: the MLSC must be contacted in all such cases.

Laser lecture aids

17. Great care should be taken over the accuracy of the laser classification of laser lecture aids: if in doubt, consult the MLSC. Class 1 or Class 2 devices should be used if at all possible.

CHAPTER 6

RANGE SAFETY — LAND, SEA AND AIR

Introduction

1. This chapter gives details of Range safety procedures covering MOD, non-MOD and foreign usage of MOD Ranges.

LASER RANGES

2. The following general instructions apply to the use of lasers during trials and training:

   a. *Class 1 and Class 2 lasers.* Class 1 and Class 2 lasers may be operated outside approved areas. However, due account should be taken of:

      (1) The presence of members of the public, whose curiosity may be such as to put them at risk by close and intense scrutiny of the laser beam and its source.

      (2) The light from these lasers may dazzle or distract motorists or aircrew, which may result in accidents.

   b. *Class 1M and Class 2M lasers*. Class 1M and Class 2M lasers may be treated as Class 1 and Class 2 lasers respectively, unless they produce hazards when viewed by optical aids (binoculars). In this case they should be treated as Class 3R lasers.

   c. *Class 3R, Class 3B and Class 4 lasers.* Class 3R, Class 3B and Class 4 lasers are only to be fired:

      (1) On MOD Service and GoCo (Government owned and contractor operated) Ranges that have been approved for the use of military lasers by the MLSC.

      (2) At sea, under the authority of captains of HM ships, in accordance with the rules promulgated in BR 1043B *Gunnery and Guided Weapon User Instructions*, when approved by the MLSC.

      (3) On non-MOD (including QinetiQ) Ranges where MOD personnel are involved, when approved by the MLSC.

      (4) At other sites for which an appropriate safety approval has been given. For such sites, advice on approvals should be given by the MLSC.

3. All lasers being operated on MOD Ranges are to be treated as weapons and require an MLSC Laser Safety Clearance Certificate before they can be used.

TARGETS AND TARGET AREAS

4. Only targets and target areas authorized by the Range control staff may be engaged by Class 1M, Class 2M, Class 3R, Class 3B or Class 4 lasers.

5. If the target is manned, the target's crew must wear correctly-fitting laser protective eyewear of the appropriate optical density. Military aircrew must wear the full aircrew equipment for the aircraft or helicopter type. If the laser protective eyewear is manufactured from glass, the aircrew must be instructed to fly with their 'bird strike' visors down. Civilian crew must be advised of the hazards involved; and if they decline to take the recommended precautions, then they are to certify in writing that they have been warned of the hazards and informed of the recommended precautions to be taken.

Diffusely-reflecting targets

6. A wide variety of diffusely-reflecting targets are engaged by lasers.

   a. All such targets must be free from glass surfaces (periscopes etc.).

   b. Man-made targets should:

      (1) Be made of hessian, sackcloth, corrugated or slatted material, with the slats rounded or angled face downward.

      (2) Use dark matt paints, and endeavour to obtain a stippled or undulating finish, possibly with the addition of sand or a similar material. No glossy or reflective finishes are to be used.

Wet targets

7. *Wet target caution.* Generally, dry military equipment and targets act as diffuse reflectors. However, a target, which is coated with a thin film of water, may act as a partial specular reflector. Due to the random orientation of the reflecting surfaces, it is not always possible to predict the direction of the reflected laser radiation and a hazard area may exist in all directions around the target: caution should therefore be taken when targets are wet. See Annex 3A paragraph 61.

8. The wet target caution does not need to be applied if the target is not capable of holding a thin film of water (e.g. hessian). The Range Safety Officer (RSO) should seek advice from MLSC as to whether or not a particular target has this characteristic.

Specularly-reflecting targets

9. When using targets that contain specularly-reflecting surfaces, such as vehicles and airborne targets (which may contain windscreens, vision blocks, etc.), the Laser Hazard Area must include an element to take account of reflection hazards.

10. If the targets to be engaged include optics, such as sights that have reflecting surfaces, then it will be necessary to produce detailed reflection hazard traces giving the position of the target relative to the laser. These traces must be incorporated into the Laser Safety Paper.

Retroreflective targets

11. The use of retroreflective materials on targets could enable significantly-reduced laser energy levels to be used for rangefinding during training. Nevertheless, such targets must only be used with suitably-filtered laser equipment’s as the majority of the energy is returned to its origin (i.e. the laser sight) with a small lateral displacement, and so present an additional hazard to the operator.

SAFETY PROCEDURES FOR LASERS ON RANGES

12. The RSO and Range staff must be fully conversant with safety regulations for the use of laser devices in training. It is the responsibility of the RSO to ensure laser operations are conducted within the Range area in such a manner as to prevent the risk of laser injury to any persons, whether military or civilian. The duties of an RSO can be found in Annex 6A.

Backstops on land Ranges

13. The use of a backstop to curtail the laser hazard is necessary when the calculated Ocular Hazard Distances (OHDs) would otherwise extend beyond the limits of the Range in which laser devices are operating. If this is not possible, then:

a. Surveillance over the entire hazard area must be maintained, to ensure it is clear of unprotected or unwarned personnel.

b. The laser operation must be able to be stopped, if unprotected persons or the general public, approaching the hazard area, could be endangered.

14. A suitable backstop can be a natural feature or made from any material which is free from reflective surfaces. However, backstops must intercept the whole laser beam subtended by the device and, in addition, allow a suitable buffer zone in both azimuth and elevation to cater for instability of laying. If no suitable backstop is available, advice is to be sought from MLSC to assess the laser hazard to military or civilian personnel who could potentially view the laser source both directly and with the use of magnifying optical instruments.

Buffer zones

15. A buffer zone around a target, the size of which depends on the ability to maintain the laser beam on the target, is required so that personnel close to the target are not exposed to laser radiation levels in excess of the protection standards. The beam-pointing accuracy of the laser device depends to a large extent upon whether the laser is mounted on a stable platform that cannot easily be moved by jarring (e.g. heavy-duty tripod, static armoured vehicle, reinforced bench mount) or an unstable platform (e.g. light tripod, hand-held, moving vehicle, ship or aircraft). The buffer zone is an angular dimension added to the beam divergence, and allows for likely pointing errors and uncertainties in the laser system performance when the equipment is in operation. Actual buffer zone dimensions will therefore vary depending on the above factors, but should not be less than the distance subtended by an angle of 2 mrad at the laser; for such small angles 1 mrad can be equated to 1 mil, the commonly-used measure of angles. The following angles are required for stationary targets engaged by:

a. A laser on a rigid mounting where accurate laying can be guaranteed, the buffer zone needs to be ±2 mrad (mils) around the target.

b. A laser on a light tripod or other unstable platform, the buffer zone is increased to ±5 mrad (mils).

c. A laser on a ship or aircraft mounted platform, the minimum buffer zone will depend upon the system pointing accuracy.

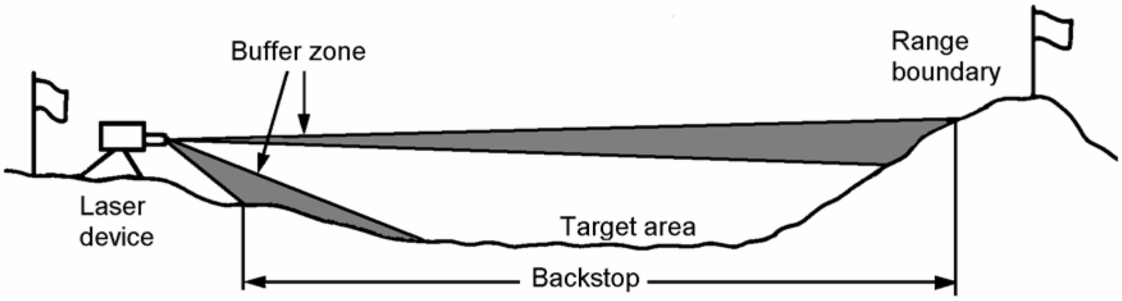
d. A hand-held laser without support, a buffer zone of at least ±30 mrad (mils) should be adopted.

Figs. 6-1 and 6-2 illustrate the siting of a laser device and the use of backstops and buffer zones.

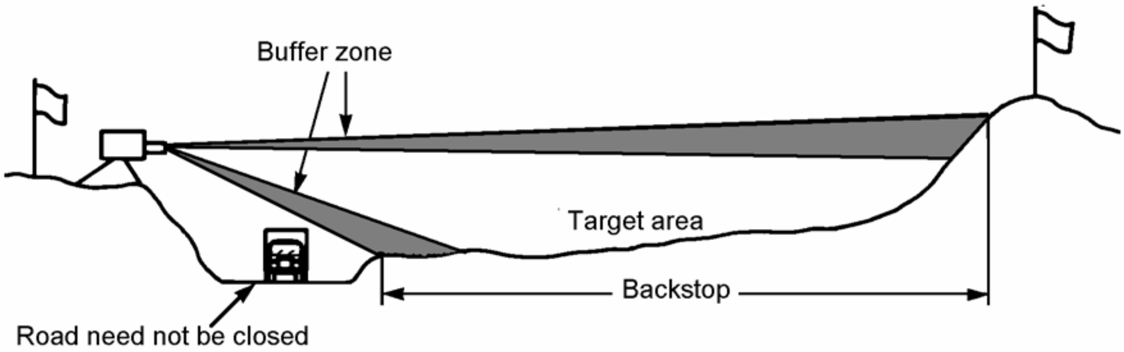
16. Suitable buffer zones for moving-target engagements and for moving-platform engagements of stationary or moving targets must be determined according to the relative circumstances. This is particularly the case for lasers mounted on helicopters, and, owing to the difficulties in determining the size of the buffer zones for this situation, reference should be made to MLSC on an individual basis.

Laser Hazard Area

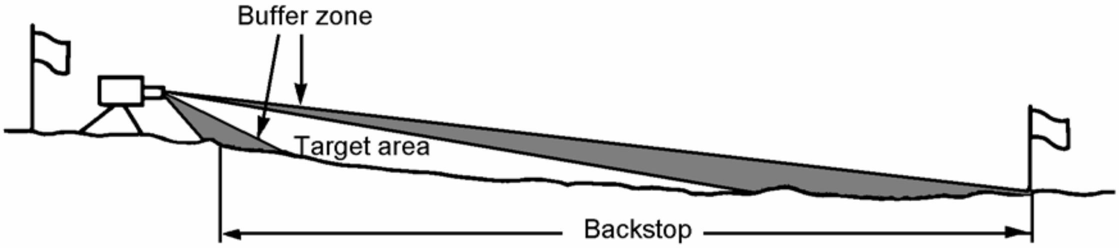
17. The basic principle of safety is that no person should be exposed unnecessarily to laser radiation, or exposed to such radiation as exceeds the MPE, unless protected by approved safety equipment. To achieve the required protection for lasers under ‘own control’, each laser system is assigned a Laser Hazard Area (LHA).



Standard backstop arrangement



Use of minimum elevation



Flat ground as a backstop

Fig. 6-1 Target areas — side view

18. The LHA is, more accurately, the entire zone in which a person could be at risk from the laser radiation. The dimensions of the LHA are dependent upon many factors, such as the OHD, the angular divergence of the beam and the pointing accuracy of the laser. The pointing accuracy, whether the laser is engaging a stationary or moving target, depends on the mounting system, the control system and on operator proficiency.

19. With certain laser systems, mostly air-to-surface, a Laser Fault Hazard Area (LFHA) may be included within the LHA. The LFHA is an area that could possibly be irradiated in the event of a severe control system malfunction that causes the laser to point in an unintended direction. Where the risk level to persons in a LFHA is sufficiently small, the MLSC may advise that laser operations be carried out under specified conditions. The surface hazard area of an air-to-surface laser is the laser beam 'footprint' and a 5 mrad buffer zone surrounding the footprint. The breakdown of the LHA into its specific sections is shown in Fig. 6-3. The Laser Hazard Area boundary can be described by appending the word 'Trace' to the terms shown, e.g. LHAT.

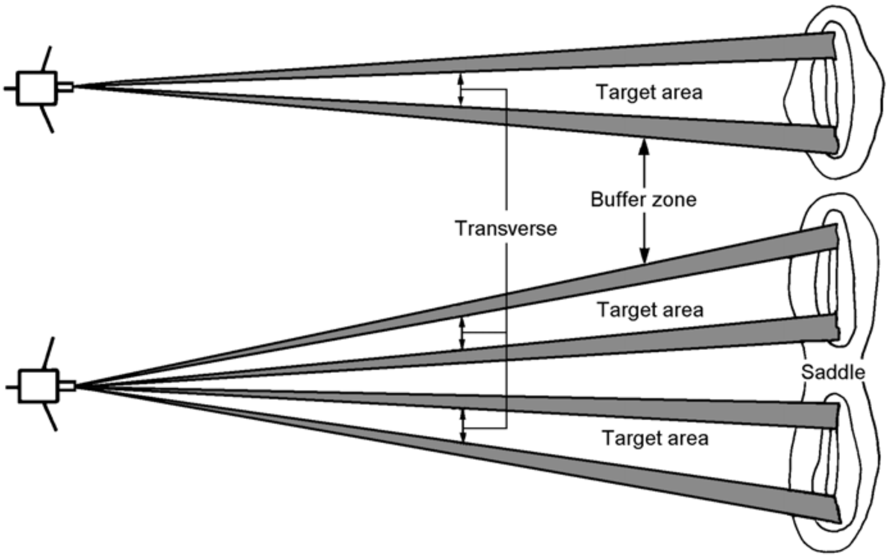


Fig. 6-2 Target areas — plan view

Magnifying optical instruments

20. Where it is known that magnifying optical instruments might possibly be used for intrabeam viewing within the area of laser operations, the hazard area must be based on the Extended OHD (EOHD) as described in Annex 3A paragraphs 37 and 38, unless using the probabilistic approach. No magnifying optical instruments are to be used anywhere within the EOHD, unless they are fitted with appropriate laser protective filters.

Personal protection

21. Whenever possible the LHA is to be cleared of all personnel during laser operations. If it is essential to fire a potentially hazardous class of laser when persons are in the hazard area, one of the following two protection measures must be adopted:

a. *Use of laser protective eyewear.* Personnel must wear authorized laser protective eyewear (or protected optics) that gives protection at the laser wavelength being used.

All authorized eyewear is marked with both the optical density and the appropriate waveband. Further, only eyewear of the relevant wavelength should be available at any one time. The term 'eyewear' includes authorized laser protective filters fitted to optical instruments. Under exceptional circumstances, it may be necessary to have two different wavelength lasers being used simultaneously or in rapid succession; if this is the case, then to avoid any confusion when more than one type of laser protective eyewear is being used, the eyewear will have to be marked very carefully. Further information on laser protective eyewear is given in Chapter 7.

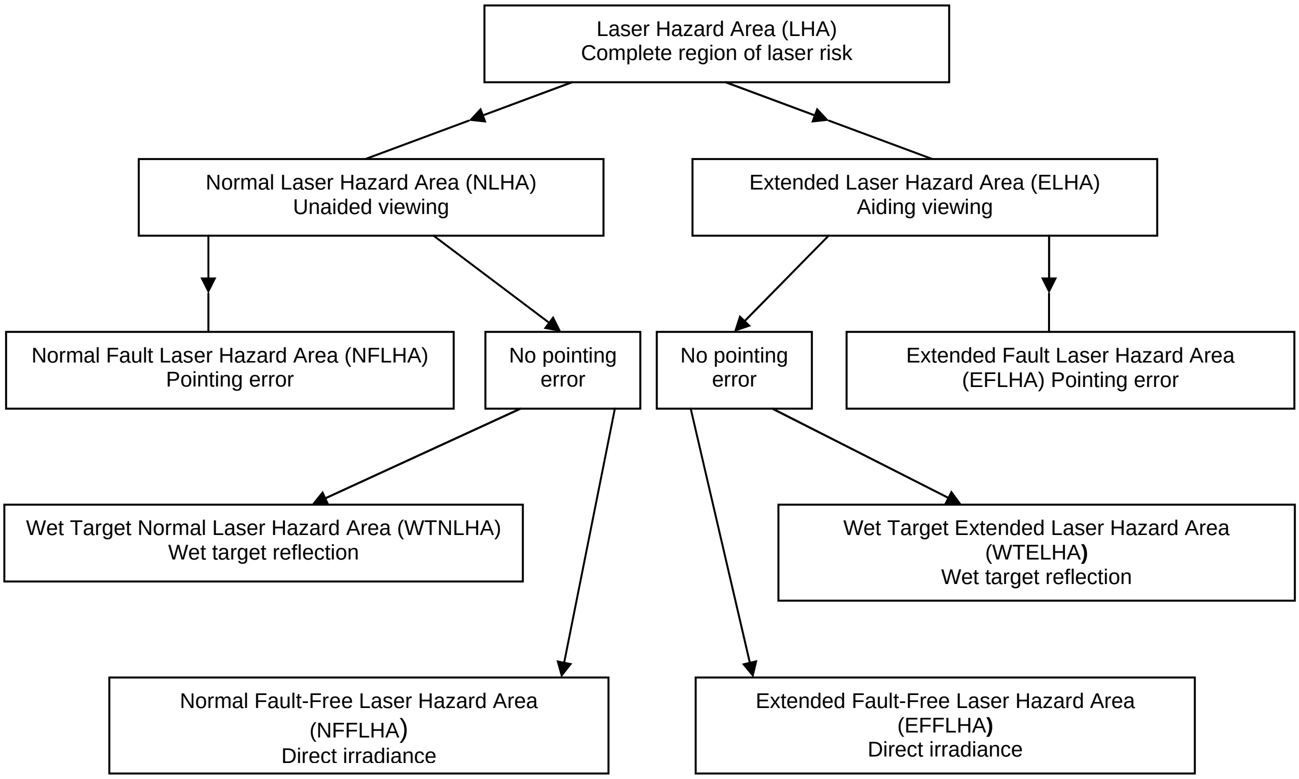


Fig.6-3 Laser Hazard Area nomenclature

b. *Warned but unprotected personnel.* Personnel who do not wear laser protective eyewear should turn their back on the laser and must not look in the direction of the laser when it is being fired. Particular account must be taken of those at risk from specular or wet target reflections, to ensure that there are no stray reflections from the direction(s) in which they are looking. This entails the use of an effective communication system between the laser firing point and all unprotected persons in the hazard area. Appropriate skin protection should also be provided and used where the beam irradiance or radiant exposure exceeds the skin MPE given in Annex 3A, Table 3A-2.

Effects of weather and night

22. No special additional precautions are required at night or during rain, snow or fog, but account should be taken of wet target caution as described in paragraphs 7 and 8 (with an example presented in Annex 3A, Example 16). The secondary hazards of dazzle and distraction are enhanced at night. Care should be taken when using lasers in the vicinity of personnel using image-intensifying equipment (e.g. night vision goggles). Extreme temperature conditions do not pose special problems.

Airborne laser operations

23. *Operator requirements.* The operator of an airborne laser (fired either from a manned aircraft or from a remotely-piloted vehicle) plays a particularly critical role in assuring safe laser operations, thereby necessitating proper operator training. The operator is responsible for:

a. Aiming and firing the laser at authorized target areas as planned and when operationally authorized, and at no other times.

b. Immediately ceasing laser operations if unwarned personnel are observed or reported in the target area.

24. *Safe operation.* The reliability of the system should be assessed to provide proper aiming of the beam only into the approved hazard area. Random malfunctions that may adversely affect system safety should be included in the assessment. To facilitate clearance for use of lasers on existing air-to-surface Ranges, the following system safety features should be considered:

a. Positive action firing switch (e.g. ‘dead man’ type) which requires a constant ‘man-in-the-loop’ control of laser operation.

b. Protection to eliminate inadvertent laser actuation.

c. An automatic disable function switch to inhibit laser firing if poor target tracking occurs or when the laser pointing angle reaches the gimbal pointing limits.

It is essential that confidence of safe operations is built up between the aircrew and the RSO.

25. *Operating log.* A detailed log of laser operations should be maintained, where practicable, to ensure compliance with laser safety restrictions.

PROTECTION PROCEDURES FOR LASERS NOT UNDER MOD CONTROL

26. The increasing use of lasers, which are not controlled by MOD, or its agencies, creates an additional risk of hazardous exposure.

27. Foreign and multinational training and exercises present a potential laser hazard. Good, early communications are therefore necessary, so that the laser hazard can be evaluated and the proper protection or action taken.

28. The maritime scenario is a particular example where Class 3R, Class 3B and Class 4 lasers may be used (e.g. by merchant and foreign naval ships), for a variety of purposes involving laser rangefinding and designating. They represent a risk to personnel on ships, in aircraft and at coastal locations.

29. In the case of cooperative vessels, again it is essential to establish good communications to establish the protection or action required.

30. For non-cooperative vessels, where there is not good communications, the problem is much greater because the laser system characteristics are likely to be unknown. A hazard to the unaided eye can extend to several miles and to beyond the horizon for aided viewing. The potential threat cannot be evaluated, and the only advice that can be given in this circumstance is to avoid eye contact.

31. The use of civil lasers may present a hazard to MOD personnel.

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CHAPTER 6 ANNEX A

LASER RESPONSIBILITIES OF A RANGE SAFETY OFFICER

1. The detailed laser responsibilities of the RSO will be laid down by the CO or head of establishment, and will normally include the following:

a. The authorizing, through the MOD Form 900 series, of the use of lasers on his Range. (Note: this is a new requirement so each RSO should consult Sec MLSC.)

b. The preparation and publication of laser standard operating procedures (SOPs) and laser Range standing orders appropriate to the type(s) of laser to be used.

c. Instructing all personnel involved in laser operations in the compliance with laser SOPs and laser Range standing orders, and ensuring that any laser is treated as a loaded weapon and handled accordingly.

d. The identification and marking of suitable sites from which laser operations may be conducted.

e. The provision of, and briefing the laser operator on, suitable targets with adequate backstops and buffer zones. All known specularly-reflecting objects on the targets and in the target area and backstops should be removed.

f. The provision of advice on the wet target caution.

g. The erection of suitable barriers and arrangements for patrols and for pickets.

h. The surveillance of the Laser Hazard Area (LHA) and the area immediately surrounding it to ensure that it is clear of unprotected and unwarned people.

i. The provision of a procedure whereby the laser operation can be stopped if unprotected/unwarned persons or the general public, approaching the LHA, could be endangered.

j. The surveillance of the airspace and seaspace within and immediately surrounding the LHA, and the method of implementing any necessary control measures (where appropriate).

k. Authorizing the use of filters and any resulting reduction in the Ocular Hazard Distance (OHD).

l. The immediate reporting of any possible/suspected overexposure to laser radiation in accordance with Annex 8A and ensuring that the individual concerned is referred at once to a qualified ophthalmologist.

CHAPTER 7

LASER EYE PROTECTION

General

1. Safety precautions should ensure that all non-essential personnel are excluded from a laser working area or hazard zone, and that all specular reflectors are removed wherever possible. The working environment should be well lit to limit pupillary size, and suitable interlocks and warning signs must be provided. Whenever possible lasers should be so constructed such that their output is totally confined (Class 1 operation) and interlocks designed to switch off power when the laser system is opened. The need to use personal eye protection against the hazardous effects of laser operation should be kept to a minimum by these engineering controls. There will, however, always be occasions when lasers are used in the field or the laser is exposed for technical reasons: personnel may then be exposed to potentially-hazardous laser radiation. Under these circumstances, adequate protective eyewear must be provided. The UK MOD has a policy of ‘warned but not protected drill’ for normal peacetime training operations, which negates the need for laser protective eyewear if the correct procedures are employed. During trials of research and development equipment and open cavity maintenance of in service lasers, goggles maybe employed.

2. Protective eyewear should be comfortable to wear, provide as wide a field of view as possible, maintain a close fit while still providing adequate ventilation to avoid problems in misting up and provide adequate visible transmittance. It should incorporate, or allow the use of, corrective lenses. It is desirable that the users normal spectacles can be worn under them. There should also be the minimal disturbance of colour discrimination. Care should be taken to avoid, as far as possible, the use of flat reflecting surfaces which might cause hazardous specular reflections. It is important that the frame and side-pieces of the eyewear should give equivalent protection to that afforded by the lenses. A protective ridge that prevents the optical surfaces being scratched when they are placed face down is a desirable design feature.

Fig. 7-1 A typical laser safety goggle. The vents on the top prevent fogging. The sides are designed to prevent laser light being admitted to the eye. The goggles can be worn over normal spectacles.

Optical density

3. Eyewear should be tested and marked with an optical density (OD), which is a measure of the ability of the lenses to attenuate a particular laser wavelength. The OD is defined as the negative of the logarithm (base 10) of the transmittance for the lens at the wavelength of interest. The higher the OD the greater the reduction in the amount of energy transmitted through the eyewear. For example, material with an OD of 3 attenuates energy by a thousand times, with an OD of 6, by a million times. Eye protection should be boldly marked with each laser wavelength at which it offers protection, and with the optical density at each wavelength. The eyewear must not lose its protective properties when irradiated by lasers, or demonstrate any induced transmission. The power rating of the laser protective eyewear should be marked on them.

4. The required OD is the level of attenuation needed to protect the eye from the laser source. It depends on many factors, including the laser power, wavelength, exposure parameters and distance from the observer. In the selection of laser protective eyewear, it is essential to know the wavelength(s) at which protection is required and the maximum power or energy density to which the eyewear will be exposed. This can be measured or calculated and will determine the OD necessary to protect the wearer. It is also important to ensure that the wearing of laser eye protection does not cause a greater hazard than the laser itself, by preventing the recognition of warning lights (such as red LEDs), by undue restriction of the field of view, or a low luminous transmission resulting in poor visibility of potentially dangerous obstacles. It should also be noted that eyewear which protects against a specific wavelength will also preclude seeing a laser beam at that wavelength, which may be essential for safety, for servicing or for scientific purposes. The degree to which visual wavelengths are transmitted is known as the VLT (Visual Light Transmission). A VLT figure of 20% will still cause a dark field of view in a well lit room. In dim environments a VLT of 30% may still cause safety problems. The usual approach to OD selection is to provide full protection for IR and UV lasers, for alignment purposes an OD with less than full protection can used in the visible band (EN 208) but this intended to protect the user from reflections and should not be used for intra-beam viewing.

Design and provision

5. Laser eye protection can be constructed from glass or a variety of plastics, or a combination of the two. Plastic lenses are more impact-resistant than glass, but are more prone to scratching. Scratching may weaken the impact resistance, and may also impair visibility. Glass lenses often have a plastic element laminated to the rear surface, to protect the eye from glass fragments in the event of breakage.

6. Eye protection is afforded by either reflecting or absorbing light at the specific laser wavelength, whilst transmitting as many of the visible wavelengths as possible. Absorption filters can be made of either an absorbing material *(*e.g*.* polycarbonate absorbs CO_2 laser radiation), or may have an absorbing dye dispersed in the lens material *(*e.g*.* organic dyes for Nd:YAG laser radiation). More recently, dielectric coatings, tuned to reflect selected wavelengths, have been used in laser eye protection. However, these are more expensive, fragile, and their OD varies with angle of incidence. Rugate filters are being developed for military laser protection goggles, these are often able to give an OD of 5 at many threat wavelengths whilst reducing the visual band absorbance away from the block band.

7. Any laser eye protection which is required to reject laser wavelengths in the visible spectrum, either by absorption or reflection, will have some degree of tint (colouration) associated with this function. Some dyed plastics used for eye protection at non-visible wavelengths (ultraviolet and infrared) may also have some associated tint, due to the broad absorption bands of the dyes used. Ideally, this colouration will be kept to a minimum.

8. When procuring or provisioning laser protective eyewear, due consideration should be given to the relevant points in the appropriate national standards for laser protective eyewear. The current standards pertaining to laser protective eyewear includes BS EN 60825, EN 207 and EN 208. The EN 207 *Personal eye-protection – Filters and eye protectors against laser radiation*, covers most high power laser applications, whilst EN208 *Personal eye-protection – Eye protectors for adjustment work on lasers and laser systems* maybe more relevant to experimental and maintenance procedures.

Goggle examination

9. The eyewear should be regularly inspected for defects such as cracks, scratches or blemishes, and tested to ensure that their OD is maintained: any scratch or defect can render the eyewear useless. The integrity of retaining straps and/or side arms should also be inspected regularly. Almost all chemicals can damage the surfaces of polymeric goggles and the goggles should only be cleaned using water and a soft optical cloth.

10. When laser goggles are not being used they are to be kept in their boxes. Every six months, and prior to use, they should be given a physical examination to check for damage. The result of this examination shall be recorded on a standard Service inspection form which should be raised as soon as the item arrives at the unit.

Operational laser eye protection

11. Military laser eye protection can be in the form of built-in filters on AFV vision ports or protection from the systems own laser in sighting optics and fire control systems. It may also take the form of PPE (Personal Protection Equipment) either as goggles or a visor on a helmet. Although it is unlikely to be possible to protect the individual against all possible laser threats, the most common threat wavelengths can be covered. In any system where a laser is used (fire control or designation) the operators optics must have protection against this laser(s) wavelength(s). The use of laser protection must not compromise the wearer's ability to maintain good situational awareness (field of view and light level). The ability to see instrumentation and warning lights (especially the colours such as red and green) for drivers and pilots will have to be considered. The military environment will require the exterior surface of any goggle or vision port to have good abrasion resistance.

12. The common wavelengths on the battlefield are considered as 1064 nm (Nd:YAG), 694 nm (Ruby) and 532 nm (Nd:YAG frequency-doubled). The US has a new goggle which gives combined ballistic and laser protection with modular filters and optional sun/glare modules. They are designed to give good field of view and be compatible with existing US personal equipment and weapon systems. One design point of note is the quick release mechanism for drivers and gunners in AFVs.

Fig. 7-2 and Fig 7-3 The US MEPS (Modular Eye Protection System) showing goggle compatibility with in service spectacles (left) and the quick adjust feature (right). The use of all three current laser filter modules can cause a problem with night vision.

CHAPTER 8

MEDICAL EXAMINATION AND LASER ACCIDENTS

Medical examination

1. The MLSC recommends that laser workers are not subject to routine eye examinations unless there has been an actual or suspected eye exposure incident. This recommendation is based on recent advise from College of Ophthalmologists and National Radiological Protection Board (NRPB)[1] which states that the risks associated with laser eye examinations outweigh the benefits in terms of detection of pathology.

2. The MLSC are expecting a guidance document from the NRPB supporting this recommendation, but this advice can be implemented immediately. There is still a requirement for organisations to have procedures to manage suspected laser incidents.

3. Information on the biological considerations, i.e. the anatomy of the eye, the effects of laser radiation on biological tissues, hazards to the eye and skin hazards can be found in Chapter 2.

Laser accident and incident reporting procedure

4. Any incident or accident on a Range or establishment resulting from the use of lasers is to be reported in accordance with Service/Agency procedures. Each Service and MOD Agency is to pass on the details of such incidents/accidents to the MLSC. The appropriate convening authority within the Service/Agency/MOD Centre is to convene a formal inquiry into any incident resulting in damage, injury or death and any significant incident, which could have resulted in damage, injury or death. The inquiry into any incident is to be conducted in accordance with the appropriate Service/MOD Agency regulations and procedures. For reporting purposes, the terms ‘laser accident’ and ‘laser incident’ have the following meanings:

a. *Laser accident*. A laser accident is an occurrence arising from the operation or functioning of laser equipment that results in injury to personnel.

b. *Laser incident*. A laser incident is a significant occurrence arising from the operation or functioning of laser equipment that could have resulted in injury to personnel.

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[1] This advice was formally reported to British Standards Institution Technical Committee EPL/76 “Optical Radiation and Laser Safety” at its meeting of 19th June 2003 and is formally recorded in the BSI minutes of that meeting

Requirements of an investigation

5. A full investigation of the circumstances of all accidents and incidents involving any possible overexposure to laser radiation, should be initiated as soon as the LSO is notified by the supervisor of the laser equipment.

6. The supervisor of the laser equipment involved in a case of suspected overexposure should take the following immediate actions:

a. Suspend all operations in the laser hazard area and notify the unit LSO.

b. Ensure that the accident conditions are left unaltered pending the subsequent investigation.

c. Ensure that the medical officer has all the information necessary for the proper care of the person(s) exposed.

d. Notify the circumstances of the accidental overexposure to the CO or head of establishment.

7. The laser accident report is to include:

a. A detailed account of the circumstances or occurrence and the events leading to it.

b. A statement as to who was in control of the laser.

c. Details of the laser concerned, including its modification state, e.g. classification, wavelength, power/energy output, mode of operation.

d. Type of protective eyewear worn, or reason for not wearing protection.

e. An assessment of the duration of overexposure, the distance from the source, whether the exposure resulted from intrabeam viewing or from reflection, and whether any optical instruments were involved.

f. Details of immediate and subsequent medical findings.

Ophthalmic examination

8. Following a suspected accident or incident, the individual is to be referred immediately to the unit medical officer who is to make a preliminary examination, consisting of those parts of the examination listed in Annex 8A paragraph 7 that are appropriate, but without the use of a mydriatic. The record of this examination will be the basis of the specialist referral to an ophthalmologist (preferably one experienced in laser-induced pathology) which is to be arranged

as soon as possible and always within 24 hours of suspected exposure. A copy of the unit LSO’s laser accident/incident report should accompany the referral. Within 7 days of the accident/incident the individual is to be reviewed by the ophthalmologist whose examination will consist of those parts of the examination listed in Annex 8A paragraph 7 that are appropriate. Further guidance to initial investigation and immediate management of laser eye damage is given at Annex 8A.

First aid treatment

9. First aid measures for overexposure to laser radiation should consist of symptomatic medical care and the protection of the injury site with a pad and bandage if necessary.

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CHAPTER 8 ANNEX A

GUIDANCE TO THE INITIAL INVESTIGATION AND IMMEDIATE MANAGEMENT OF LASER EYE DAMAGE

1. This annex describes the medical screening examinations[2] and action to be taken following suspected laser accidents and incidents.

Description of potential ocular damage

2. *Cornea.* The effect of ultraviolet radiation on the cornea is to produce epithelial injury, a condition that can be painful and visually handicapping. Minimal corneal lesions should heal within a few days, but meanwhile they can produce a decrement in visual performance. Far-infrared radiation is also mainly absorbed by the cornea, producing immediate burns at all corneal layers. An infrared laser can produce a lesion which results in permanent scarring of the cornea. If the energy is sufficiently high, the cornea can be perforated which may lead to loss of the eye.

3. *Retina and Choroid*. The retina is transparent to most wavelengths of visible light. However, laser energy in the visible range can produce inner retinal damage, although this is mainly secondary to the much greater absorption and destruction that takes place in the deeper and more-pigmented tissue, the retinal pigment epithelium. When the retinal pigment epithelium absorbs sufficient laser energy, local thermal coagulation of adjacent photoreceptors and other structures of the retina also occurs. The surrounding retina will also be affected by oedema. These processes result in a scotoma (blind spot) that varies in size depending upon the extent of the retinal damage. Vision may not be disturbed significantly by small retinal burns away from the fovea. Visible and near-infrared lasers of sufficient power can produce haemorrhage in the choroid and disruption of the overlying retina. The visual loss from this haemorrhage may be quite severe. The blood may also move into the vitreous of the eye through the disrupted retina, where it may obstruct the passage of light through the ocular media. If extensive or centrally located, such haemorrhages can produce a significant loss of vision.

Laser effects on vision

4. *Glare*. Visible laser light can interfere with vision even at low energies that do not produce eye damage. Exposure to continuous wave or rapidly pulsed, visible laser light can produce a glare, such as that produced by the sun, searchlights, or headlights.

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[2] Extracted and adapted from Surgeon General's Policy Letter 15/99 (covering AIR STANDARD 61/115/14A): The initial investigation and immediate management of laser eye damage in aircrew.

5. *Flashblindness and After-image*. Visible laser light can also produce a lingering, yet temporary, visual loss associated with spatially localized after-effects, similar to that produced by flashbulbs. Like glare, these after-effects can occur at exposure levels that do not cause eye damage. One after-effect, known as "flashblindness," is the inability to detect or resolve a visual target following exposure to a bright light. Another after effect, often confused with flashblindness, is "after-image". After-images are the perception of light, dark, or coloured spots after exposure to a bright light. Small after-images, through which one can see, may persist for minutes, hours, or days. After-images are very dynamic and can change in colour, size, and intensity depending upon the background being viewed. It is difficult to correlate the colours of after-images with specific laser wavelengths. After-images are often annoying and distracting but are unlikely to cause a visual decrement.

6. *Visual Loss from Damage*. The permanent damage caused by UV, visible, and IR lasers can cause variable degradations in vision, proportional to the degree of damage. Corneal damage may significantly degrade vision due to increased light scatter from opacities or due to gross rupture. In addition, iritis, seen in association with corneal injuries, may cause photophobia, pain, and miosis (small pupil). In the case of retinal damage, the severity of visual loss will depend upon the proximity and extent of the damage to the fovea. Functionally significant loss of vision usually occurs only if the burn directly affects the fovea. The expected minimum burn size (30–100 µm) for a low-power exposure to the fovea will have variable effects on visual acuity depending on location, with either no effect or a reduction in vision to approximately 6/12 for high-contrast targets. On the other hand, a direct laser burn to the fovea would definitely alter vision. If the retinal damage includes haemorrhages, the visual loss may be more profound, as the blood may block the passage of light to uninjured portions of the retina. Central visual field defects caused by damage to the posterior pole will be noticeable and may be distracting or disabling, depending upon whether the fovea and, thus, visual acuity are affected. These central defects can be detected and characterized quite accurately with the Amsler Grid. A laser's light energy is likely to affect both eyes, unless one is occluded or otherwise protected, because the laser beam's diameter, at operationally significant distances, will be wider than the head.

Symptoms

7. Symptoms will vary depending upon the location and severity of injury. Patients may give a history of experiencing glare, flash blindness, decreased vision, pain, or any combination. When seen by medical personnel, they may continue to complain of after-images, blurred vision, photophobia, pain, or profound loss of vision. Obvious lesions, such as corneal and/or retinal burns and retinal haemorrhages make the diagnosis more certain, especially when accompanied by a history of seeing bright, coloured lights.

Examination

8. *Details of the screening examination.* The pre-placement examination is to be carried out by an ophthalmologist or optometrist (preferably one experienced in laser-induced pathology), following referral by the unit medical officer. The examination should consist of those of the following aspects deemed relevant by the ophthalmologist/optometrist but must include a posterior pole colour photograph of each eye.

The military/occupational health documents must be annotated with the location of storage of the photographs.

- *a.* Ocular and relevant general medical history.
- *b.* Assessment of visual acuity for distant vision, with and without correction if worn.
- *c.* Tests of colour vision (both red/green and blue/yellow).
- *d.* Assessment of the central visual field/macular function using the Amsler grid.
- *e.* Examination of the cornea, lens and fundus oculi (with use of mydriatic when appropriate) by direct ophthalmoscopy or slit-lamp microscope.
- *f.* Further examinations may be performed at the ophthalmologist's discretion, e.g. peripheral visual field testing or biomicroscopic examination of the eye.

9. *Additional notes to the screening examinations*.

- *a.* Single services are responsible for the training of medical staff and provision of equipment to enable the examinations detailed at paragraph 7 to be performed.
- *b.* Aircrew and vehicle drivers will be unfit to fly and drive respectively following the use of mydriatics. A short-acting mydriatic is preferred.

Physical findings

10. No clinical findings may be apparent if only subjective symptoms (glare, flash blindness, or after images) have occurred as the result of a non-damaging exposure, or if there is retinal damage or haemorrhage outside the fine vision area of the posterior pole. The latter may be asymptomatic and not seen with the direct ophthalmoscope. Malingerers will generally have either no objective findings, or symptoms out of proportion to objective findings. Clinical findings due to damage may be variable and include the following: isolated rows or groups of retinal burns; retinal/vitreous haemorrhages; and superficial or deep burns of the cornea.

Treatment

11. *Corneal Injuries*. The treatment for corneal burns is the same as for burns of other aetiologies, namely, the use of antibiotic coverage and eye dressings. Patch only the eye with the injured cornea. If the eye has been ruptured, the likelihood of saving it is low. The eye should be protected from external pressure by a metal eye shield. Do not put any eye drops or ointments on a ruptured eye. The patient should be kept physically quiet in a supine position. Priority of evacuation depends on the severity of injury and the likelihood of saving the eye. Analgesia may be required for patient comfort. Topical anaesthetics should never be given to the patient for self-medication, but they may be used by the physician to aid in the examination and treatment of non-ruptured globes.

12. *Retinal Injuries*. At present, the treatment for laser injuries to the retina/choroid is not well-defined. Ocular and oral corticosteroids have not been proven effective for the treatment of retinal burns or haemorrhages. The use of eye patches for retinal damage is discouraged. Patching deprives the patient of his/her residual vision which may be quite good. It also has the effect of magnifying the visual impairment to the patient and increasing their dependence on others. Personnel with vitreous haemorrhages should be maintained on bed rest with their head positioned so that the blood settles away from the visual axis, particularly for the first few days. Patients with retinal damage currently have a low evacuation priority.

Medical debriefing for suspected laser incidents and accidents

13. *Circumstances*.

a. Did you see a bright light? How bright was it, like the Sun, a full moon, or car headlights at night? Were there other light sources on the platform (such as running lights or navigation lights) and were they brighter or dimmer?

b. What was the colour(s) of the light? Was it uniform in colour? Did the colour(s) change during the exposure?

c. Did the light come on suddenly, and did it become brighter as you approached it?

d. Was the light continuous or did it seem to flicker? If it flickered, how rapidly and regularly?

e. For how long was the light on?

f. From what did the light emanate? Was it from an aircraft, tank, etc.?

g. How would you describe the brightness of the light? Was it equally bright in all areas or was it brighter in one area?

h. How far away was the light source? Was it moving?

i. At what time of the day did the incident occur?

j. What was the visibility? What were the atmospheric conditions: clear, overcast, rainy, foggy, hazy, sunny?

k. What surfaces were between the light source and your eyes - windscreen, glasses, head-up display, lenses, binoculars, filters, visors, or goggles? Describe them in great detail (e.g. ×2 binoculars, aircrew visor (clear, tinted or laser-protective), prescription glasses, night vision devices, hazy windscreen, etc). Were any of these devices damaged or caused to malfunction by the light?

l. Did you try to move out of the light beam? What evasive manoeuvres did you attempt? Did the beam follow you as you tried to move away? How successful were you in avoiding it?

m. Was the light coming directly from its source or did it appear to be reflected off other surfaces? Did you notice multiple sources of light?

n. Did the light fill your cockpit or compartment? How wide was the beam at its source? How wide was the beam once it reached you?

14. *Possible Effects*.

a. How long did you look into the light beam? Did you look straight into the light beam or off to the side?

b. What tasks were you doing when the exposure occurred? Did the light prevent or hamper you from doing those tasks, or was the light more of an annoyance?

c. Were both eyes exposed? If not, describe the difference between the light exposures (for example, one eye was shielded or closed, or on the side away from the light beam). Describe any difference in the effects on either eye.

d. Were you startled or disoriented when the light appeared?

e. Was the light so bright that you had to blink or squint, close your eyes, or look away? Was the light painful? Describe the pain. For how long did the pain persist after the light exposure?

f. Was your vision affected while the light was on? How much of your visual field was affected? What types of things could you see or not see? Did you notice the colour of instruments or targets change? Did the changes to your vision remain constant or vary during the exposure? If the light source was mounted on a platform (aircraft, ground vehicle or building), how much of the platform was obscured? [Note: Recommend that the word "dazzle" not be used because its definition varies greatly; "glare" is the preferred word].

g. Did your vision remain affected after the light was extinguished? If so, for how long and how did you estimate the time? How much of your visual field was affected? What types of things could you see or not see (watch, hand, vehicle instruments, map, etc.)? Did you notice after-images ("spots before your eyes")? If so, how long did they last, what did they look like, and what were their size, shape and position in your visual field? Describe how your vision was affected 10 seconds after the light exposure ended, 30 seconds afterwards, 1 minute, 2 minutes, etc.?

h. Were there any lingering (hours or days) visual effects? If so, were the effects continuous or intermittent? Did you have problems reading or seeing in low light conditions? How long until you were able to see normally again?

i. Did you notice any reddening, warming, or burns to your skin?

j. Describe the condition of your vision before the incident? Do you wear spectacles or contact lenses? Are you taking any medications?

k. Did you seek medical attention following the incident? Where and when were you examined? Who performed the examination? Was the examiner a medical officer, ophthalmologist or optometrist? What were the clinical findings?

CHAPTER 8

MEDICAL EXAMINATION AND LASER ACCIDENTS

Medical examination

1. The MLSC recommends that laser workers are not subject to routine eye examinations unless there has been an actual or suspected eye exposure incident. This recommendation is based on recent advise from College of Ophthalmologists and National Radiological Protection Board (NRPB)[1] which states that the risks associated with laser eye examinations outweigh the benefits in terms of detection of pathology.

2. The MLSC are expecting a guidance document from the NRPB supporting this recommendation, but this advice can be implemented immediately. There is still a requirement for organisations to have procedures to manage suspected laser incidents.

3. Information on the biological considerations, i.e. the anatomy of the eye, the effects of laser radiation on biological tissues, hazards to the eye and skin hazards can be found in Chapter 2.

Laser accident and incident reporting procedure

4. Any incident or accident on a Range or establishment resulting from the use of lasers is to be reported in accordance with Service/Agency procedures. Each Service and MOD Agency is to pass on the details of such incidents/accidents to the MLSC. The appropriate convening authority within the Service/Agency/MOD Centre is to convene a formal inquiry into any incident resulting in damage, injury or death and any significant incident, which could have resulted in damage, injury or death. The inquiry into any incident is to be conducted in accordance with the appropriate Service/MOD Agency regulations and procedures. For reporting purposes, the terms ‘laser accident’ and ‘laser incident’ have the following meanings:

   a. *Laser accident*. A laser accident is an occurrence arising from the operation or functioning of laser equipment that results in injury to personnel.

   b. *Laser incident*. A laser incident is a significant occurrence arising from the operation or functioning of laser equipment that could have resulted in injury to personnel.

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[1] This advice was formally reported to British Standards Institution Technical Committee EPL/76 “Optical Radiation and Laser Safety” at its meeting of 19th June 2003 and is formally recorded in the BSI minutes of that meeting

Requirements of an investigation

5. A full investigation of the circumstances of all accidents and incidents involving any possible overexposure to laser radiation, should be initiated as soon as the LSO is notified by the supervisor of the laser equipment.

6. The supervisor of the laser equipment involved in a case of suspected overexposure should take the following immediate actions:

- *a.* Suspend all operations in the laser hazard area and notify the unit LSO.
- *b.* Ensure that the accident conditions are left unaltered pending the subsequent investigation.
- *c.* Ensure that the medical officer has all the information necessary for the proper care of the person(s) exposed.
- *d.* Notify the circumstances of the accidental overexposure to the CO or head of establishment.

7. The laser accident report is to include:

- *a.* A detailed account of the circumstances or occurrence and the events leading to it.
- *b.* A statement as to who was in control of the laser.
- *c.* Details of the laser concerned, including its modification state, e.g. classification, wavelength, power/energy output, mode of operation.
- *d.* Type of protective eyewear worn, or reason for not wearing protection.
- *e.* An assessment of the duration of overexposure, the distance from the source, whether the exposure resulted from intrabeam viewing or from reflection, and whether any optical instruments were involved.
- *f.* Details of immediate and subsequent medical findings.

Ophthalmic examination

8. Following a suspected accident or incident, the individual is to be referred immediately to the unit medical officer who is to make a preliminary examination, consisting of those parts of the examination listed in Annex 8A paragraph 7 that are appropriate, but without the use of a mydriatic. The record of this examination will be the basis of the specialist referral to an ophthalmologist (preferably one experienced in laser-induced pathology) which is to be arranged

as soon as possible and always within 24 hours of suspected exposure. A copy of the unit LSO’s laser accident/incident report should accompany the referral. Within 7 days of the accident/incident the individual is to be reviewed by the ophthalmologist whose examination will consist of those parts of the examination listed in Annex 8A paragraph 7 that are appropriate. Further guidance to initial investigation and immediate management of laser eye damage is given at Annex 8A.

First aid treatment

9. First aid measures for overexposure to laser radiation should consist of symptomatic medical care and the protection of the injury site with a pad and bandage if necessary.

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CHAPTER 8 ANNEX A

GUIDANCE TO THE INITIAL INVESTIGATION AND IMMEDIATE MANAGEMENT OF LASER EYE DAMAGE

1. This annex describes the medical screening examinations[2] and action to be taken following suspected laser accidents and incidents.

Description of potential ocular damage

2. *Cornea.* The effect of ultraviolet radiation on the cornea is to produce epithelial injury, a condition that can be painful and visually handicapping. Minimal corneal lesions should heal within a few days, but meanwhile they can produce a decrement in visual performance. Far-infrared radiation is also mainly absorbed by the cornea, producing immediate burns at all corneal layers. An infrared laser can produce a lesion which results in permanent scarring of the cornea. If the energy is sufficiently high, the cornea can be perforated which may lead to loss of the eye.

3. *Retina and Choroid*. The retina is transparent to most wavelengths of visible light. However, laser energy in the visible range can produce inner retinal damage, although this is mainly secondary to the much greater absorption and destruction that takes place in the deeper and more-pigmented tissue, the retinal pigment epithelium. When the retinal pigment epithelium absorbs sufficient laser energy, local thermal coagulation of adjacent photoreceptors and other structures of the retina also occurs. The surrounding retina will also be affected by oedema. These processes result in a scotoma (blind spot) that varies in size depending upon the extent of the retinal damage. Vision may not be disturbed significantly by small retinal burns away from the fovea. Visible and near-infrared lasers of sufficient power can produce haemorrhage in the choroid and disruption of the overlying retina. The visual loss from this haemorrhage may be quite severe. The blood may also move into the vitreous of the eye through the disrupted retina, where it may obstruct the passage of light through the ocular media. If extensive or centrally located, such haemorrhages can produce a significant loss of vision.

Laser effects on vision

4. *Glare*. Visible laser light can interfere with vision even at low energies that do not produce eye damage. Exposure to continuous wave or rapidly pulsed, visible laser light can produce a glare, such as that produced by the sun, searchlights, or headlights.

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[2] Extracted and adapted from Surgeon General’s Policy Letter 15/99 (covering AIR STANDARD 61/115/14A): The initial investigation and immediate management of laser eye damage in aircrew.

5. *Flashblindness and After-image*. Visible laser light can also produce a lingering, yet temporary, visual loss associated with spatially localized after-effects, similar to that produced by flashbulbs. Like glare, these after-effects can occur at exposure levels that do not cause eye damage. One after-effect, known as “flashblindness,” is the inability to detect or resolve a visual target following exposure to a bright light. Another after effect, often confused with flashblindness, is “after-image”. After-images are the perception of light, dark, or coloured spots after exposure to a bright light. Small after-images, through which one can see, may persist for minutes, hours, or days. After-images are very dynamic and can change in colour, size, and intensity depending upon the background being viewed. It is difficult to correlate the colours of after-images with specific laser wavelengths. After-images are often annoying and distracting but are unlikely to cause a visual decrement.

6. *Visual Loss from Damage*. The permanent damage caused by UV, visible, and IR lasers can cause variable degradations in vision, proportional to the degree of damage. Corneal damage may significantly degrade vision due to increased light scatter from opacities or due to gross rupture. In addition, iritis, seen in association with corneal injuries, may cause photophobia, pain, and miosis (small pupil). In the case of retinal damage, the severity of visual loss will depend upon the proximity and extent of the damage to the fovea. Functionally significant loss of vision usually occurs only if the burn directly affects the fovea. The expected minimum burn size (30–100 µm) for a low-power exposure to the fovea will have variable effects on visual acuity depending on location, with either no effect or a reduction in vision to approximately 6/12 for high-contrast targets. On the other hand, a direct laser burn to the fovea would definitely alter vision. If the retinal damage includes haemorrhages, the visual loss may be more profound, as the blood may block the passage of light to uninjured portions of the retina. Central visual field defects caused by damage to the posterior pole will be noticeable and may be distracting or disabling, depending upon whether the fovea and, thus, visual acuity are affected. These central defects can be detected and characterized quite accurately with the Amsler Grid. A laser's light energy is likely to affect both eyes, unless one is occluded or otherwise protected, because the laser beam’s diameter, at operationally significant distances, will be wider than the head.

Symptoms

7. Symptoms will vary depending upon the location and severity of injury. Patients may give a history of experiencing glare, flash blindness, decreased vision, pain, or any combination. When seen by medical personnel, they may continue to complain of after-images, blurred vision, photophobia, pain, or profound loss of vision. Obvious lesions, such as corneal and/or retinal burns and retinal haemorrhages make the diagnosis more certain, especially when accompanied by a history of seeing bright, coloured lights.

Examination

8. *Details of the screening examination.* The pre-placement examination is to be carried out by an ophthalmologist or optometrist (preferably one experienced in laser-induced pathology), following referral by the unit medical officer. The examination should consist of those of the following aspects deemed relevant by the ophthalmologist/optometrist but must include a posterior pole colour photograph of each eye.

The military/occupational health documents must be annotated with the location of storage of the photographs.

a. Ocular and relevant general medical history.

b. Assessment of visual acuity for distant vision, with and without correction if worn.

c. Tests of colour vision (both red/green and blue/yellow).

d. Assessment of the central visual field/macular function using the Amsler grid.

e. Examination of the cornea, lens and fundus oculi (with use of mydriatic when appropriate) by direct ophthalmoscopy or slit-lamp microscope.

f. Further examinations may be performed at the ophthalmologist’s discretion, e.g. peripheral visual field testing or biomicroscopic examination of the eye.

9. *Additional notes to the screening examinations*.

a. Single services are responsible for the training of medical staff and provision of equipment to enable the examinations detailed at paragraph 7 to be performed.

b. Aircrew and vehicle drivers will be unfit to fly and drive respectively following the use of mydriatics. A short-acting mydriatic is preferred.

Physical findings

10. No clinical findings may be apparent if only subjective symptoms (glare, flash blindness, or after images) have occurred as the result of a non-damaging exposure, or if there is retinal damage or haemorrhage outside the fine vision area of the posterior pole. The latter may be asymptomatic and not seen with the direct ophthalmoscope. Malingerers will generally have either no objective findings, or symptoms out of proportion to objective findings. Clinical findings due to damage may be variable and include the following: isolated rows or groups of retinal burns; retinal/vitreous haemorrhages; and superficial or deep burns of the cornea.

Treatment

11. *Corneal Injuries*. The treatment for corneal burns is the same as for burns of other aetiologies, namely, the use of antibiotic coverage and eye dressings. Patch only the eye with the injured cornea. If the eye has been ruptured, the likelihood of saving it is low. The eye should be protected from external pressure by a metal eye shield. Do not put any eye drops or ointments on a ruptured eye. The patient should be kept physically quiet in a supine position. Priority of evacuation depends on the severity of injury and the likelihood of saving the eye. Analgesia may be required for patient comfort. Topical anaesthetics should never be given to the patient for self-medication, but they may be used by the physician to aid in the examination and treatment of non-ruptured globes.

12. *Retinal Injuries*. At present, the treatment for laser injuries to the retina/choroid is not well-defined. Ocular and oral corticosteroids have not been proven effective for the treatment of retinal burns or haemorrhages. The use of eye patches for retinal damage is discouraged. Patching deprives the patient of his/her residual vision which may be quite good. It also has the effect of magnifying the visual impairment to the patient and increasing their dependence on others. Personnel with vitreous haemorrhages should be maintained on bed rest with their head positioned so that the blood settles away from the visual axis, particularly for the first few days. Patients with retinal damage currently have a low evacuation priority.

Medical debriefing for suspected laser incidents and accidents

13. *Circumstances*.

a. Did you see a bright light? How bright was it, like the Sun, a full moon, or car headlights at night? Were there other light sources on the platform (such as running lights or navigation lights) and were they brighter or dimmer?

b. What was the colour(s) of the light? Was it uniform in colour? Did the colour(s) change during the exposure?

c. Did the light come on suddenly, and did it become brighter as you approached it?

d. Was the light continuous or did it seem to flicker? If it flickered, how rapidly and regularly?

e. For how long was the light on?

f. From what did the light emanate? Was it from an aircraft, tank, etc.?

g. How would you describe the brightness of the light? Was it equally bright in all areas or was it brighter in one area?

h. How far away was the light source? Was it moving?

i. At what time of the day did the incident occur?

j. What was the visibility? What were the atmospheric conditions: clear, overcast, rainy, foggy, hazy, sunny?

k. What surfaces were between the light source and your eyes - windscreen, glasses, head-up display, lenses, binoculars, filters, visors, or goggles? Describe them in great detail (e.g. ×2 binoculars, aircrew visor (clear, tinted or laser-protective), prescription glasses, night vision devices, hazy windscreen, etc). Were any of these devices damaged or caused to malfunction by the light?

l. Did you try to move out of the light beam? What evasive manoeuvres did you attempt? Did the beam follow you as you tried to move away? How successful were you in avoiding it?

m. Was the light coming directly from its source or did it appear to be reflected off other surfaces? Did you notice multiple sources of light?

n. Did the light fill your cockpit or compartment? How wide was the beam at its source? How wide was the beam once it reached you?

14. *Possible Effects*.

a. How long did you look into the light beam? Did you look straight into the light beam or off to the side?

b. What tasks were you doing when the exposure occurred? Did the light prevent or hamper you from doing those tasks, or was the light more of an annoyance?

c. Were both eyes exposed? If not, describe the difference between the light exposures (for example, one eye was shielded or closed, or on the side away from the light beam). Describe any difference in the effects on either eye.

d. Were you startled or disoriented when the light appeared?

e. Was the light so bright that you had to blink or squint, close your eyes, or look away? Was the light painful? Describe the pain. For how long did the pain persist after the light exposure?

f. Was your vision affected while the light was on? How much of your visual field was affected? What types of things could you see or not see? Did you notice the colour of instruments or targets change? Did the changes to your vision remain constant or vary during the exposure? If the light source was mounted on a platform (aircraft, ground vehicle or building), how much of the platform was obscured? [Note: Recommend that the word "dazzle" not be used because its definition varies greatly; "glare" is the preferred word].

g. Did your vision remain affected after the light was extinguished? If so, for how long and how did you estimate the time? How much of your visual field was affected? What types of things could you see or not see (watch, hand, vehicle instruments, map, etc.)? Did you notice after-images ("spots before your eyes")? If so, how long did they last, what did they look like, and what were their size, shape and position in your visual field? Describe how your vision was affected 10 seconds after the light exposure ended, 30 seconds afterwards, 1 minute, 2 minutes, etc.?

h. Were there any lingering (hours or days) visual effects? If so, were the effects continuous or intermittent? Did you have problems reading or seeing in low light conditions? How long until you were able to see normally again?

i. Did you notice any reddening, warming, or burns to your skin?

j. Describe the condition of your vision before the incident? Do you wear spectacles or contact lenses? Are you taking any medications?

k. Did you seek medical attention following the incident? Where and when were you examined? Who performed the examination? Was the examiner a medical officer, ophthalmologist or optometrist? What were the clinical findings?

CHAPTER 9

THE PROCUREMENT AND DISPOSAL OF LASERS

LASER PROCUREMENT

1. No lasers, or associated procedures, may be introduced into service (including all trials and development) without the approval of the MLSC. Each project manager (or procurement authority where there is no official project manager) should therefore approach the MLSC at the earliest opportunity in the procurement process (see Annex 9A); in particular, to establish the level of detail in any required documentation and the level of funding which the project must provide.

2. The project manager is responsible for preparing and publishing the safety instructions. For Class 1 or Class 2 laser systems, proof of classification is required by the MLSC: this should be done in the form of a Laser Safety Paper (LSP). Where there is any doubt regarding a laser's classification, or intended use, and when procuring Class 1M, Class 2M, Class 3R, Class 3B and Class 4 lasers, the project manager is responsible for preparing a formal Laser Safety Paper (LSP) for consideration by the MLSC. It should be in the form laid out in Annex 9B.

Laser Safety Paper

3. The MLSC's principal aim is to ensure that all pertinent safety aspects associated with a laser system coming under its jurisdiction have been considered, and that personnel, the general public and materiel are not hazarded by use of that device. In order to achieve this, the MLSC must be satisfied that each laser:

a. is *proven* to be safe under all reasonable conditions, or

b. can be *shown* to be safe under all reasonable conditions, or

c. is used in an acceptably-safe manner.

4. No formal action is required by the MLSC if a laser is to be used only within enclosed facilities which have already been approved (by the appropriate authority) for use with lasers of the assigned (and proven) Class, in accordance with the British Standard. Such approval of a facility by an authority would be to show compliance with the HSW Act, and this approval should be presented to the MLSC. Typical facilities are enclosed test and maintenance bays and enclosed laser laboratories. In these cases, specific local laser rules may need to be generated (see Annex 10C).

5. Where a laser is to be used outside approved enclosed facilities, such as on a Range or inside an unapproved building, formal MLSC approval must be sought. An LSP is required from the MOD or Private Venture (PV) project manager. The MLSC's satisfaction is then recorded by the issue of an LSCC. Fig. 9-1 summarizes the route to be taken by a project manager or sponsor when dealing with a particular laser system (see also paragraph 3). Annex 9B describes the content and format of the LSP. If the MLSC has already proved the system to be Class 1 or Class 2, then the MLSC only requires proof of this (e.g. a previously-approved LSP).

Laser Safety Clearance Certificate

6. When the MLSC is satisfied that the draft LSP provides a sufficient level of information and that due care and attention is being taken, then an Interim LSCC will be issued to allow use of the equipment to go ahead, albeit on a limited and highly-controlled basis. Such uses include: trials to develop the system and/or define in-Service safety procedures, user familiarization trials, limited initial use of the equipment by Service personnel, and one-off trials for system evaluation purposes or for laser-based measurements outside approved enclosed facilities. Special care needs to be taken if the laser is used in a demonstration at this early stage in its development.

7. If a laser system is for eventual general use, the MLSC will issue a Final LSCC when it is satisfied that the laser system design is complete and that all relevant information has been provided, along with the appropriate safety procedures (if applicable), to allow such use of the equipment (in general or site-specific areas). Final LSCCs are copied to:

a. The project manager (IPT).

b. The relevant Equipment Capability Customer (ECC).

c. The user, for the Laser Safety Officer.

d. DSTL Radiological Protection Service (DRPS), for their annual review.

e. Defence Land Ranges Safety Committee (DLRSC).

f. The Ranges where the laser is to be used, for the Range Safety Officer.

g. The MLSC.

WHAT IS THE SYSTEM'S PURPORTED LASER CLASSIFICATION?

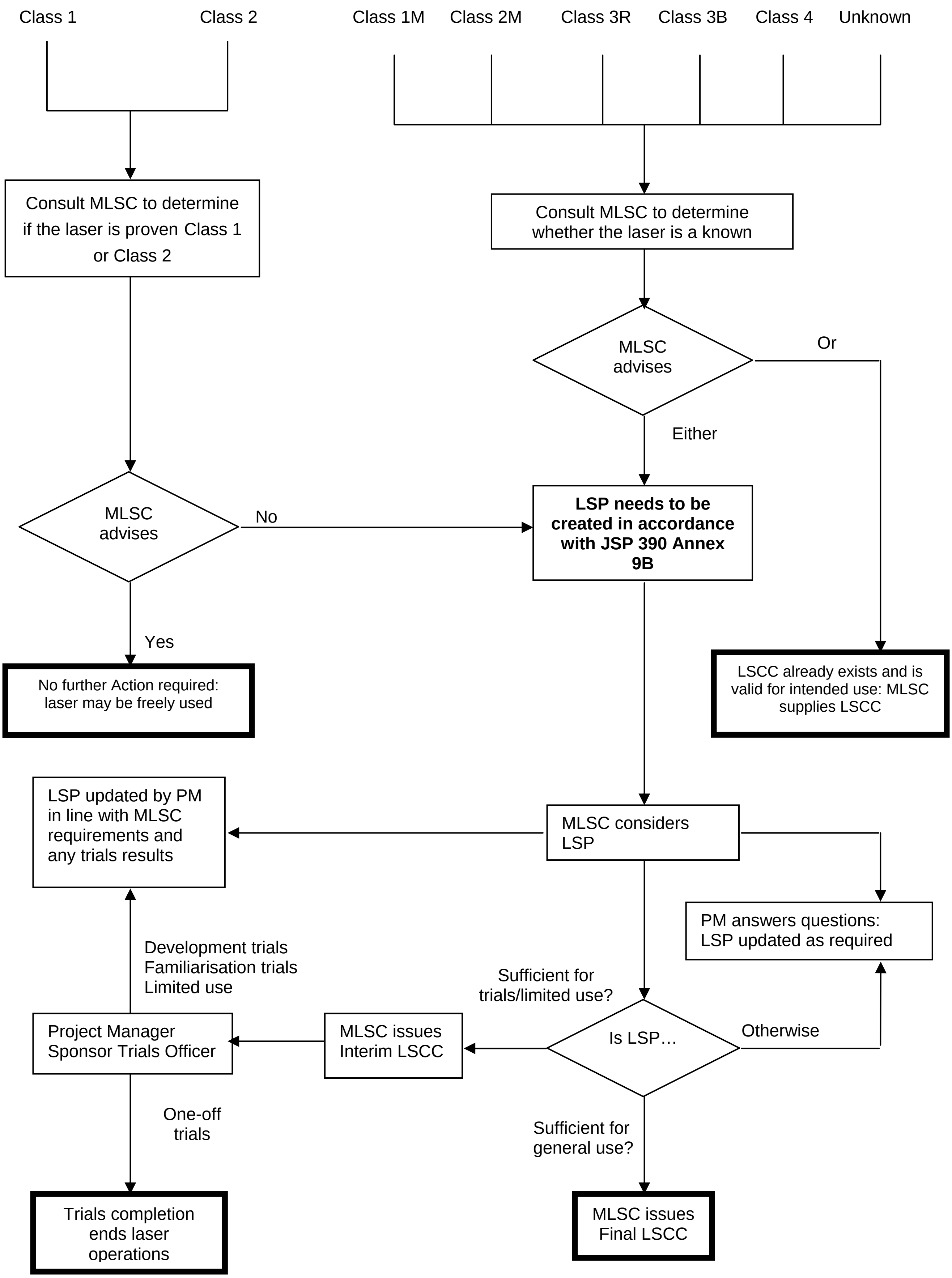

Fig. 9-1 Project manager's LSP application to the MLSC

LASER HOLDINGS

8. As part of their annual radiation equipment holding survey, DRPS will ask each establishment/regiment/unit to report their holding of lasers, giving the full names of the lasers (including Part Number) and number of each laser held.

LASER DISPOSAL

9. Owing to the safety and, on occasion, security implications associated with the disposal of obsolete or irreparable laser equipment, the MOD equipment sponsor (or user where there is no sponsor) is responsible for ensuring that specific disposal instructions are issued and complied with. Disposal instructions should ensure that there is no possibility of the equipment, or of any of its components, being returned to a functioning condition without proper authorization. **The MLSC is to be approached before any disposal of lasers.**

CHAPTER 9 ANNEX A

STATEMENT BY LASER SYSTEM PROJECT MANAGER

The following letter gives guidance for the format that the laser project manager should use to give the MLSC initial warning of the requirement for a Laser Safety Clearance Certificate (LSCC) from the MLSC in accordance with JSP 390 Chapter 9.

To: The MLSC

Request for initial laser safety clearance for ______________(laser system)

Reference: JSP 390 Chapter 9

1. ____(IPT project manager or sponsor) for _____________________________________ (laser system) will prepare a Laser Safety Paper (LSP) for consideration by the MLSC in accordance with JSP 390 Chapter 9. Financial provision for this laser safety clearance has been made.

2. The LSP will be an interim statement of all the safety-related hazards arising from the use of the laser system, and of the safety features that are incorporated in the design and procedures to prevent injury to personnel likely to be so hazarded.

3. This system is scheduled to be used at ________________________________ on ___________ (date) and it is requested that the Interim MLSC Laser Safety Clearance Certificate is issued before that date.

Signed _____________________________________

Project Manager.

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CHAPTER 9 ANNEX B

LASER SAFETY PAPER

Introduction

1. The MLSC has inspected a significant number of Laser Safety Papers (LSPs) each year, which have often been found wanting in terms of the information necessary for the safety of a laser system, in operation and during maintenance, to be fully assessed. The consequent redrafting and resubmitting of LSPs for MLSC consideration has often involved several iterations before a satisfactory presentation of the relevant information was achieved, which added to the cost of and delay to getting laser systems into operation.

2. Reasons for the rejection of an LSP have been many and various, but often involved the inadvertent omission, or the incomplete presentation, of information important to the system hazard assessment.

3. The aim of these guidelines is to establish a standard format for the presentation of laser safety information in the LSP, and provide advice on the information content of its various sections. It should be noted that these guidelines are not necessarily exhaustive; LSPs for individual systems will differ depending on the equipment type, class, deployment and environment in which they are used. Essentially, the points that need to be considered are:

a. Equipment details.

b. System safety features.

c. Hazard evaluation.

d. Operational tactics.

e. Laser operators.

f. Range safety features.

g. Test and maintenance features.

h. Other requirements (e.g. laser goggles, use of magnifying optics).

4. In all cases, an LSP should be readable and understandable, containing only sufficient detail to allow the safety of the laser system to be assessed. Extensive details of a system should be referenced as separate documents. If there is any doubt, or if any aspect is unclear, then advice should be sought from the MLSC at the earliest opportunity.

5. In this annex, the term laser system means an assembly of components incorporating one or more lasers, with their appropriate laser energy source, together with the host platform (if relevant) and the operator or operating system, where these can affect the nature and direction of the laser output.

Format

6. As each laser system will differ from others in its individual characteristics, the precise information content of the LSP for a particular system will also differ from that in other systems' LSPs, according to the degree and type of hazard the system presents to the user or nearby personnel. However, a standard format is recommended to ensure that all relevant information is presented.

7. The LSP must have the following sections:

   a. *Section 1 – Laser system description*. Providing a brief description (where appropriate) of the system requirement, installation and use of the equipment in all relevant modes, and a description of its design and safety features.

   b. *Section 2 – Laser system output.* Providing an overall description of the laser system output and its hazards, including its laser classification and (if applicable) Ocular/Skin Hazard Distances.

   c. *Section 3 – Laser system operation.* Providing a description of the laser system operation in its intended environment, and of the precautions necessary to ensure safe usage of the equipment.

   d. *Section 4 – Laser system test and maintenance.* Providing a description of the precautions required to ensure safety of personnel during testing and maintenance of the system.

8. The LSP should also have annexes containing:

   a. *Annex A – Laser system classification.* The detailed calculation of the laser classification for the system.

   b. *Annex B – Laser system hazard distances.* The detailed calculation of the Ocular/Skin Hazard Distances for the system (if relevant).

   c. *Annex C – Probabilistic risk assessment.* The detailed probabilistic risk analysis (if relevant).

d. *Annex D – Normal operation analysis.* An analysis to support/justify the information provided on the system during normal operation; in particular, the accuracy of directional control (if relevant).

e. *Annex E – Faulty operation analysis.* An analysis to support/justify the information provided on the system in the case of a fault occurring.

f. *Annex F – Software*. An analysis to support the conformity of any software; in particular, that of safety critical software.

9. Extra annexes may be added as necessary to provide further description or evidence of the system design and/or operation, in support of the rest of the document.

10. If the resulting LSP is likely to be classified higher than UK Restricted, then the MLSC should be consulted.

Section 1 — Laser system description

11. The information provided by this section should be generally descriptive, and should not duplicate information given elsewhere in the LSP.

12. Section 1 should cover the following:

a. *Requirement.* Brief details of the laser requirement (e.g. the staff requirement).

b. *Application.* A list of the applications/installations in which the laser is intended to be used/sited.

c. *Design and construction.* A brief description of the design and construction of the system, and of its controls and operation, along with the location of the system within the establishment/platform (if relevant).

d. *Design safety features.* Brief details of any design features which affect the system's safety. These include:

(1) *Laser fire switch.* A description of the means by which laser firing can be initiated. For Class 3B and Class 4 laser systems, details of any key-operated master control, which enables the laser to fire (a laser-enable key), should be provided.

(2) *Anomalous/unintentional output.* A description of any features incorporated to minimize or reduce output radiation beyond that of the main laser beam (e.g. secondary beams, collateral radiation), to avoid beam irregularities or unintentional/unwanted laser modes, or to prevent the system from firing except when

intended.

(3) *Protective housings.* Details of any protective housings to prevent human access to laser irradiation in excess of the applicable Accessible Emission Limit (AEL) for the assigned Class. In particular, details should be given as to whether any non-interlocked removable service panels in the protective housing are secured in such a way that their removal requires the use of special tools which cannot be substituted by ad hoc devices such as coins, screwdrivers, files, etc. If a supra-Class 1 system incorporates fibre-optics as part of its design, then any fibre-optic cable connection should be considered as part of the protective housing, and any special tools for its disconnection described.

(4) *Safety interlocks.* Details of any safety interlocks or switches to prevent laser firing when any part of the protective housing is removed, or when the system is not in a particular mode of operation, and whether or not these are fail-safe. The description should also include details of:

(i) The presence of any override switches to allow laser firing without certain safety features, in particular for test and maintenance (e.g. aircraft systems designed not to fire when on the ground, scanning systems in which the scanning action must be disabled to allow testing), or for less-restrictive use (e.g. operational training where such safety features reduce the operational effectiveness of the system, such as automatic switch-off of a laser designator when the system loses track of the target).

(ii) Whether procedures for a safe system of working have been specified in the event of a safety interlock being overridden.

(iii) Whether there is a visible or audible warning whenever the laser is energized and a safety interlock overridden.

(iv) Whether it is possible to cancel the visible or audible warnings when removing / replacing the protective housing.

(v) (In the case of Class 3B or Class 4 lasers) the incorporation of any remote interlock connectors for the connection of external safety devices, such as entrance-door switches of laser test and maintenance areas.

(5) *Location of controls.* Details of the location of the system controls, and whether their adjustment and/or operation will expose personnel to more than the applicable Class 1 AEL.

(6) *Viewing optics and viewports.* Details of any viewing optics or viewports in the system which allow access to laser radiation, and of any devices present to prevent exposure in excess of the applicable Class 1 AEL. In particular:

(i) If filters are used in the operator's sight to prevent hazardous laser radiation returning through the sight from specular reflections or from other nearby lasers, or to prevent internal reflection hazards, then details should be given as to whether the filters significantly impair visibility and whether it is possible for the optics to be reassembled without the filters following maintenance.

(ii) If shutters or variable attenuation are used, then details should also be given on whether human access to laser radiation in excess of the applicable Class 1 AEL is prevented when the shutter is opened or attenuation varied; conversely, whether opening of the shutter or variation of the attenuation is prevented if human access to such laser radiation is possible.

(7) *Beam pointing control.* Details of the operator control of the laser pointing direction, particularly in the case of the system mounted on a mechanical platform (which itself could be mobile). In these cases, the following should be considered:

(i) The possibility of the laser pointing direction and the sightline becoming misaligned during motion.

(ii) The mechanical limits of the laser pointing direction and the associated design slew rates, and whether automatic inhibition of the laser is employed when these limits are reached. If no such mechanism is present, then details of any (preferably at least two) independent means of disabling the laser should be given.

(iii) In automatic tracking systems, whether there is any automatic inhibition of the laser if target track is lost or if the design tracking slew rates are exceeded.

Attention must be given to the effects on laser pointing direction control if any of the above an be overridden (e.g. for better operational training).

(8) *Training mode.* Details of any provisions to reduce the potential hazard to a more practical level to allow training (e.g. through the use of filters, beam expanders, diffusers or frequency-altered output, different lasers or increased monitoring of the training area).

(9) *Non-laser hazards.* Details of any non-laser hazard associated with the system, and of any control of such hazards. These hazards may arise from the system itself or from the operation of the system (e.g. electrical hazards, X-ray production and the presence of radioactive, cryogenic, toxic, corrosive or inflammable substances).

(10) *Software.* If the safety integrity of the laser system is wholly or partly reliant on software, then the elements having those functions should:

(i) be identified;

(ii) be shown to conform to a rigorous mathematical specification of the function(s), with supporting details in a separate annex if necessary (Annex F); and

(iii) be shown, in its safety role, to be validated against the overall system requirements.

Information should be given to identify whether the software is officially "safety critical software"; or, if not, whether it is critical to the safety of the system.

(11) *Warning devices and labels.* For Class 3 and Class 4 laser systems, details of any audible or visible warnings given when the laser is operating, or (if relevant) when its capacitors are not fully discharged. Details should also be given if the laser and its power source are separately housed, and, if they are separated by more than 2 m, whether they are both provided with warning devices. Details of any laser hazard warning labels attached to the system should also be given. Information should be provided as to whether visible warnings and labels may be viewed directly without exceeding the applicable Class 1 AEL or through protective eyewear.

e. *Compatibility.* The compatibility of the laser system with other adjacent equipment (e.g. EMC), and vice versa, should be briefly detailed.

f. *Checks.* Details of how the laser system is to be checked before use to ensure that the laser emission (including any leakage) does not exceed the designated Class AEL, and to ensure correct alignment of the beam pointing direction.

g. *Publications*. The titles and references of any publications giving any other relevant details of the laser system.

h. *Contact Point.* The name, address and telephone number of an authorized person to respond to queries about the laser system.

Section 2 — Laser system output

13. This section of the LSP should describe the nature of the system's output and the potential hazards, taking into account the relevant *Health and Safety at Work* and *Control of Substances Hazardous to Health* legislation.

14. Details of laser output parameters should be given in accordance with the British Standard, be unambiguous and justified, and take into account the natural variation between individual examples of the system (giving the worst-case values wherever possible, i.e. the values which result in the greatest hazard).

15. Section 2 should include:

a. *Laser description and classification.* A description of the laser source unit, including the manufacturer's model number, and the laser classification of *all* aspects of the system (i.e. the laser unit and the system in all firing modes) in accordance with the British Standard. A formal derivation of the laser classification(s) should be given at Annex A to the LSP.

b. *Laser type.* A statement of the laser source type (e.g. solid state, gas, etc.), whether it is repetitively-pulsed/modulated or CW (with modulating mechanism, if applicable), and whether or not the source can be considered as an extended source (with a supporting description, if so).

c. *Wavelength.* The wavelength(s) at which the laser can operate, at any stage within the laser unit (e.g. the laser may be Raman-shifted, so that both the wavelengths of the pumping laser and of the transformed output should be given), together with any spread in wavelengths.

d. *Power/energy.* The maximum radiant power (for CW lasers) or radiant energy (for pulsed lasers) output for both the laser unit and the system output in all firing modes. Peak (integrated) radiant intensity should also be given. For extended laser sources, values of peak (integrated) radiance should be given. Corresponding values for any extraneous output (e.g. secondary beams) from the system should also be quoted. Proof of all values should be provided at Annex D.

e. *Pulse modulation*. If the laser output is pulsed or otherwise modulated, then the minimum and maximum pulse duration, together with the maximum pulse repetition frequency (PRF), in all firing modes should be given. For lasers with a coded output, the total number of pulses in one burst is also required.

f. *Firing time.* For lasers operating in any mode other than single-shot, the maximum firing time, and/or the maximum number of pulses which can be produced in one operation of the system, is required. If the maximum firing time is less than the applicable timebase for laser classification, and the classification is dependent on this firing time, then the safeguards ensuring this maximum must be given.

g. *Beam shape.* Details of the beam shape (e.g. gaussian, flat-topped, etc.) should be given, as well as the peak-to-average ratio and whether the laser beam is entirely divergent and/or in the far-field on emergence, for all aspects of the system output. The description should also give values of minimum beam diameter and beam divergence (at the 1/*e*-points) for all aspects and firing modes of the system, even if the beam is non-circular (for example, it is possible to treat an elliptically-shaped beam as having a diameter of $a_x \times a_y$ mm and a divergence of $\varphi_x \times \varphi_y$ mrad). These details should take into account possible variation with operating time. Proof of the quoted details should be provided, if at all possible, at Annex D.

h. *Laser system output faults.* Brief details of any reasonably-foreseeable system faults (or operator error) which could cause an adverse change in any of the above parameters. Any fail-safe mechanisms to prevent unwanted or undesirable laser emissions must be described. Where such mechanisms are not employed then the above parameters must take into account possible system faults. If the system is, or is to be, incorporated into a host system (e.g. aircraft, vehicle, ship or other platform), then possible adverse effects of faults in the host system must be described and accounted for in the worst-case laser parameters. If appropriate, a *failure mode effects analysis* (FMEA) should be performed to establish the probability of exceeding the quoted output and to allow the MLSC’s consideration of its acceptability. Any supporting analysis should be placed at Annex E.

i. *Ocular/Skin Hazard Distances*. For Class 1M, Class 2M, Class 3 and 4 lasers, the appropriate Ocular Hazard Distances (OHDs) for the system should be quoted, with a formal derivation (in accordance with Annex 3A) at Annex B.

Section 3 — Laser system operation

16. The purpose of this section is to describe the precautions, and any special or additional procedures or requirements, needed to ensure the safe use of the laser system in its operational environment, where unprotected persons may be exposed to hazardous emissions from the laser system. The content will therefore vary considerably according to the complexity of the system under consideration (from a simple fixed-installation laser rangefinder to an air-to-ground laser target designator with a sophisticated laser directional control system).

17. Section 3 should consider the following details:

a. *Laser sightline directional control*. Brief details should be provided on whether the laser sightline is fixed or steerable during laser firing. In the latter case, details should also be given on whether the laser is hand-held or controlled by manual or automatic electromechanical means.

b. *Laser sightline limits*. Where the laser sightline can be pointed in an arbitrary direction, details should be given on the maximum pointing limits relative to the platform, together with details of any mechanical/software device to switch off the laser when these limits are reached. If the laser sightline is fixed relative to a potentially moving platform, then details should also be given on the arc swept by the laser sightline during any reasonably-foreseeable platform manoeuvre.

c. *Laser sightline accuracy.* Details should be provided on the accuracy with which a laser is aimed in a given direction during laser firing, when the laser system and platform are operating normally. These should take into account the stability of the platform supporting the system including, as relevant, the effects of crosswinds, vibration, shock, etc., plus operator factors such as workload and experience. If the laser sightline can be moved during laser firing, then the following additional factors should also be considered:

  (1) The accuracy of the directional control under all modes of operation (manual or automatic). If required, a supporting analysis (e.g. software control diagram) should be provided at Annex D.

  (2) Any special procedures required of the operator to ensure that the laser sightline is maintained on the intended target.

  (3) Any factors which could affect automatic systems to maintain the laser sightline on the intended target (e.g. poor visibility, low target contrast, poor system calibration).

  (4) The possibility of the laser firing in an inadvertent direction while the system is operating without fault (e.g. for an automatic tracking system, tracking of the wrong object). Details should then be provided on:

    (i) The precautions taken to prevent (or minimize the possibility of) this situation happening.

    (ii) The time taken before laser firing stops, either automatically or manually under worst-case workload conditions.

(iii) The extent to the deviation from the intended direction before laser firing stops (allowing for possible platform movement).

(iv) The energy emitted in an unintended direction before the laser stops firing.

(v) Whether laser firing can recommence when the intended laser sightline direction is regained.

d. *Laser/operator sightline.* If relevant (e.g. where the operator's view of the target is through an optical/imaging system), the worst-case difference between the sightlines for the operator and the laser, which are not common, should be given. Details of any operator display, by which laser sightline directional information may be communicated should also be given.

e. *Laser directional control faults.* Details, as applicable, should be provided on any reasonably-foreseeable system (including the platform) faults which could cause deviation of the laser sightline from its intended direction. Details provided should cover, as relevant:

(1) The effect of hardware/software faults on the laser sightline movement (e.g. motor freeze or runaway, or spurious commands).

(2) The time taken before the laser stops firing after a laser directional control fault occurs (automatically or manually, under worst-case workload conditions and taking into account operator experience).

(3) The extent of the deviation from the intended direction before laser firing stops, taking into account maximum possible slew rates of the control system and possible platform movement.

(4) The energy emitted in an unintended direction before the laser stops firing, taking into account the reaction times of the operator and/or the system.

(5) Whether all relevant failure mechanisms are monitored automatically, so that the operator may know of such a failure, or may not know as the case may be.

(6) Any indications to the operator that a failure has occurred.

(7) Any fail-safe mechanisms (software, electrical or mechanical) to control the amount and direction of laser radiation emitted following a fault.

(8) The probability of a relevant fault occurring during one use of the system.

f. *Laser Hazard Area.* For supra-Class 1 laser systems, details on the operating environment of the system should be given, together with any procedures or instructions to avoid hazarding the general public, personnel and materiel, during training of operating personnel, preparation for firing, and firing. Although Class 2 lasers are nominally eye-safe, due to the human aversion response, some precautions may be necessary to prevent purposeful staring into the visible beam by a (possibly distant) observer.

Details should cover, where they could be appropriate:

(1) The use of Laser Hazard Area Traces (including traces for wet targets), buffer zones and backstops, and/or any mechanical means of confining the hazard area (e.g. end-stop pegs, tubes, screens, baffles). Note that the use of screens or baffles may present a diffuse hazard.

(2) The use of warning signs, floor/deck markings, or barriers to prevent unprotected personnel or vehicles from straying into the hazard area.

(3) The use of procedures to monitor the hazard area, and the means to stop the laser firing if the hazard area becomes, or is about to be, occupied.

(4) The use of procedures to ensure only authorized use of the laser system; in particular, the control of any laser-enable key or similar device (particularly in the case of crew-served weapons).

(5) The use of procedures to ensure the safety of the general public and personnel working near the laser system.

(6) The use of identified safety personnel.

(7) The use of procedures in the event of the possible use of magnifying instruments by unprotected persons near or observing the laser system.

(8) The use of protective eyewear by personnel working in the vicinity of the laser system; in particular, the provision of such eyewear for the crew of manned targets.

(9) The precautions taken to prevent potentially-hazardous reflections from surfaces on the laser platform (e.g. by masking). Reflections can also be expected from: wet, specular or retroreflective targets; water and other specular surfaces in the laser field-of-view; and diffuse screens and baffles which are used near the laser to restrict the laser field-of-view.

(10) The use of audibly or visually prominent warnings (other than those designed into the system) of laser firing and/or malfunction during operational use.

(11) The use of atmospheric measurements to ensure that the laser system's hazards are kept within identified limits, to validate the atmospheric characteristics which are being used to reduce calculated Ocular/Skin Hazard Distances (e.g. visibility).

(12) The use of precautions to protect any sensitive or susceptible equipment near the laser system; in particular, the protection of any inflammable liquids and gases (including oxygen systems). These could include the monitoring of the levels of inflammable gases or vapours (and increased oxygen levels) which could increase the possibility of explosive combustion during laser operation.

Section 4— Laser system test and maintenance

18. Laser systems should normally be tested and maintained in suitable facilities which meet the requirements of the British Standard (see Chapter 9 paragraph 7). Special attention should be paid to the testing of the laser system 'in the field', away from such facilities.

19. Such considerations should suffice to protect personnel and materiel during:

a. Training of maintenance personnel.

b. Test and maintenance, be it on land, at sea or in the air.

However, there may be some special features of the laser system, or special requirements, which need to be taken into account. Details of any such features or requirements should be given, together with any appropriate procedures and/or instructions, covering the same aspects that would be considered in the operational environment (see paragraph 17*f.*).

20. Details should be given on the frequency with which the laser system should be maintained, and by whom (i.e. in-house maintenance department, manufacturer or authorized agent). A statement should be provided to give assurance that the worst-case performance parameters quoted in the LSP will not be exceeded when the laser system is maintained.

21. When any modification is proposed for the laser system, then the LSP must be reviewed and, if necessary, updated for reconsideration and recertification by the MLSC. This applies throughout the life of the laser and its associated equipment.

Annex A — Laser system classification

22. This annex should provide a mathematical derivation of the laser classification for all aspects of the system, according to the British Standard. The mathematical derivation should be sufficiently explicit to allow the MLSC to be assured that the assigned Class is correct.

Annex B — Laser system hazard distances

23. This annex should provide, if applicable, a mathematical derivation of:

a. The appropriate Maximum Permissible Exposures (MPEs) for the laser wavelengths and ocular and/or skin exposures under consideration, according to the British Standard.

b. The appropriate hazard distances for ocular and skin exposure to the laser radiation, taking into account:

(1) the nature of the source (i.e. point or extended),

(2) maximum firing times,

(3) maximum observer exposure periods,

(4) the possible use of magnifying optics by an observer,

(5) the effect of atmospheric scintillation, and

(6) any other relevant factors (e.g. reflections, including wet targets).

c. The appropriate OD values for attenuating filters for potential observers of the laser energy (whether direct or by reflection).

24. The calculation of hazard distances should adhere to that described in Annex 3A as far as possible, with any assumptions fully justified. Deviations from that prescription may be acceptable to the MLSC, if fully explained and justified.

Annex C — Probabilistic risk assessment

25. As explained in Chapter 3, the practical use of a laser system may be highly restricted if the calculated, deterministic, hazard distances are too large for the environment in which the laser system is to be used. Annex 3B gives an alternative, probabilistic, approach to assuring the MLSC that the risk to a potential observer is acceptably small. If such an approach is used for the laser system under consideration, then that method must be fully described in Annex C to the LSP, in addition to Annex B (detailing the calculation of the hazard distances).

Annex D — Normal operation analysis

26. This annex should provide sufficient evidence and analysis to justify the information provided on the normal operation of the system; in particular, the laser output power/energy, beam divergence, beam shape, and beam pointing accuracy. This may require measurements and/or formal system/operator analysis.

Annex E — Faulty Operation Analysis

27. This annex should provide sufficient evidence and analysis to justify the information provided on the system in the case of a fault; in particular, the effects on the laser output parameters and beam directional control. This may require measurements and/or a formal FMEA.

Annex F — Software

28.This annex should provide sufficient evidence and analysis to show that any safety critical software conforms to applicable safety standards (e.g. Def Stan 00-55 and Def Stan 00-56), and that any software which is critical to safety has been appropriately validated as fit for its purpose.

CHAPTER 10

THE PROCUREMENT, USE AND DISPOSAL OF MEDICAL LASERS

LASER PROCUREMENT

1. No lasers used for medical purposes, or associated procedures, may be introduced into service without the approval of the MLSC. The sponsor, or the user where there is no sponsor, is to advise the MLSC of the details of the proposed new laser system in an LSP as detailed in Annex 10A. Provided the methodology has been agreed by the MLSC and the LSP is acceptable to the MLSC, an LSCC will be issued by the MLSC Chairman as detailed in Annex 10B.

2. If in doubt, sponsors and users should seek advice from DRPS on the production of LSPs.

LASER SAFETY PRECAUTIONS FOR MEDICAL APPLICATIONS

3. *Medical laser operating precautions.* The local rules for medical laser use are to be designed to prevent unauthorized operation of the laser and to control the conditions under which it is used, thereby minimizing risk to staff and to patients. Example precautions are detailed in paragraphs 6 to 12 and an example of a set of local rules is set out in Annex 10C. Further information on clinical applications and examples of local rules are given in the Department of Health publication *Guidance on the Safe Use of Lasers in Medical Practice* (HMSO ISBN 011 32085 7).

4. Staff who are present in the clinic/treatment room during use of the laser are to be aware of the nature of the hazard involved, and they are to ensure that the requirements for their own and their patient’s safety are being observed.

5. It should be noted that typical medical lasers involve the use of a Class 4 treatment laser and a Class 2 alignment laser.

6. *Initial room preparation*.

   a. *Approved room.* The equipment will only be used and stored in a designated, approved, clinic/treatment room.

   b. *Warning sign.* A warning sign, as detailed in the British Standard, must be fixed to the outside of the entrance before treatment commences. It must be removed after laser treatment has ceased and the laser has been isolated.

7. *Fixtures, fittings and furnishings*.

a. The area towards which the laser points shall be kept clear of reflective or flammable fittings, fixtures or furnishings. All equipment not required during a laser clinic should be removed before the clinic is begun.

b. *Fire extinguisher.* A fire extinguisher is to be provided immediately outside the entrance door. It shall be of the appropriate type and have that capacity which is recommended by the fire officer.

8. *Layout of equipment in approved room.* The layout of the equipment within the laser treatment room is to comply with the following requirements:

a. The laser must *at all times* be positioned so that the laser beam exit port points in the direction of a clear wall and never towards the door.

b. The main console must be positioned so that the operator can easily reach the *on/off* switches and see the *power level meter* from the normal operating seated position. The console must also be positioned well clear of the beam and as far to the rear of the laser as possible.

c. Any associated equipment must be positioned in such a way that it cannot interfere with the laser system.

d. Cables, tubes, etc., must be routed in such a way that, if snagged by personnel, there is no chance of the laser beam direction being suddenly deflected mechanically. If necessary, anchor points for cables, tubes, etc., are to be provided.

9. *Personnel*.

a. A register is to be kept of personnel authorised to operate the equipment and of medical staff who are trained to be in the laser treatment room.

b. One authorized operator shall be nominated by the unit/establishment LSO to ensure that the register is maintained and to assume overall control of the installation and its safe operation. Each operator is responsible for ensuring that all staff present have been properly instructed about laser hazards, and is also responsible for the safety of any visitors present.

c. Operators and assistants must sign statements that they have read and understood the local laser safety rules. These statements should be kept by the unit LSO.

10. *Deployment of personnel in the room*.

a. When the laser is in operation, the number of people in the room is to be kept to a minimum. All personnel except the attending nurse, the operator and the patient, should keep behind the laser and well clear of the operator. Whenever possible, CCTV should be used for teaching. When it is necessary for a visitor to observe procedure by direct vision (close over the operator's shoulder), only one such person at a time is to do this and he or she must wear protective eyewear.

b. The attending nurse may be with the patient in front of the laser beam but must wear protective eyewear and should face away from the beam while the laser is being operated whenever possible.

c. Under normal conditions, *all personnel* in the room, except the operator and the patient *must wear protective eyewear.*

11. *Patient handling.* Following an explanation of the procedure, the patient will be positioned for examination. The laser *must not* be switched on until this positioning is completed. It must be switched off after treatment and before any other equipment is moved.

12. *Security*.

a. Whenever the equipment is unattended by a registered operator, the control console must be switched off and the key withdrawn and kept in the safe custody of the nominated responsible person.

b. The key shall be clearly labelled.

LASER DISPOSAL

13. The Defence Medical Services Equipment Supply Depot at Ludgershall is responsible for ensuring that specific disposal instructions are issued and complied with. Disposal instructions should ensure that there is no possibility of the equipment, or of any of its components, being returned to a functioning condition without proper authorization.

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CHAPTER 10 ANNEX A

LASER SAFETY PAPER FOR MEDICAL LASERS

Each Laser Safety Paper (LSP) will differ, depending on the type and class of the equipment which will be used and the intended method of deployment. A recommended list of headings is provided below. Where applicable, the user should expand or contract them as necessary, depending on the degree of sophistication of the laser system and the possible magnitude of the hazard resulting from its use. Typical medical lasers comprise a Class 4 treatment laser and a Class 2 alignment laser, an LSP should therefore (if relevant) take into account the presence of more than one laser in the equipment.

Introduction

1. a. A brief paragraph on the requirement.

b. List of applications or installations in which the laser system will be used.

c. Brief description and/or diagram of the design and construction of the laser system and its location. (Do not duplicate here detail which is given under paragraph 2.)

Safety hazard and compatibility aspects of the laser system

2. *a*. Detailed description of the laser device in accordance with the British Standards.

(1) Description.

(2) Type.

(3) Wavelength.

(4) Peak power, and pulse energy.

(5) Peak irradiance or peak energy density.

(6) Modulations, pulse duration, PRF.

(7) Beam diameter and divergence at the 1/e-points.

(8) Optical devices fitted in the beam path.

(9) The class of the laser, the NOHD and, if required the extended NOHD.

The mean, standard deviation and limiting production values for parameters (3) to (7) above.

b. A statement of the safety features that have been designed into the laser system to avoid hazard to personnel and materiel during the following operations:

(1) Training of maintenance and operating personnel.

(2) Test and maintenance.

(3) Preparation for firing.

(4) Firing.

c. If a safety feature relies on drills/procedures, appropriate detail from the relevant maintenance instruction or publication.

d. The title and reference of the publication giving details of the laser system.

e. Compatibility with adjacent equipment when using the laser.

f. Supporting documentation to show how the equipment is to be checked before use to ensure that laser emission/leakage does not exceed the designated Class limits.

Due account must be taken of Section 6 of the *Health and Safety at Work; etc., Act, 1974*, which details the general safety requirements of manufacturers as regards articles and substances for use at work.

Laser work area safety features

3. When compiling comments on paragraph 2, include any special or additional safety requirements that will be required for the laser system to cover the following applicable points:

a. Provision of instructions regarding Laser Hazard Areas including buffer zones and backstops.

b. Use of magnifying instruments.

c. Reflections.

d. Masking of reflective surfaces.

e. Audible/visual alarms.

f. Warning signs.

g. Barriers, restrictions or floor markings.

h. Safety key.

i. Protection of anaesthetic gases and oxygen systems.

j. Safety interlocks for test/maintenance protective enclosures.

k. Special lighting for areas containing test/maintenance protective enclosures.

l. Provision of laser protective eyewear (goggles) for patients, operators (or maintainers when required) to include the optical densities (at the appropriate specific wavelengths for the equipment) and frame translucencies of the protection.

m. The local rules for medical laser firing are described in Chapter 10 paragraph 3. An example is given in Annex 10C.

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CHAPTER 10 ANNEX B

LASER SAFETY CLEARANCE CERTIFICATE FOR MEDICAL LASERS

The content will normally follow the example given below.

To: Laser Safety Officer

Ref:______________________

Date:_____________________

Copy to:
Surgeon General Department HR2
DRPS
MLSC

Interim/Final Laser Safety Clearance Certificate for _________________ (laser system)

1. The MLSC has assessed the safety of __________________ (laser system) to ensure that the arrangements satisfy the current safety standards for the protection against hazards from laser radiation.

2. The MLSC is satisfied that the necessary safety arrangements have been incorporated in the design and that, where a hazard exists external to the system, appropriate procedures have been established (or appropriate regulations have been promulgated).

3. (Detail of special considerations or other relevant material will be included in Appendices and references here.)

4. The MLSC has, therefore, agreed that this Laser Safety Clearance Certificate shall be issued in respect of _______________________ (laser system) for _____________________ (either general or specific Service use, or specific trials).

Signed _________________________
Chairman MLSC

Appendices

1. Laser Safety Paper No.______________
2. (As required)

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CHAPTER 10 ANNEX C

EXAMPLE OF LOCAL RULES

The following example is presented here as a guide to format only.

Local rules for the use of Sharplan 733 surgical laser

This laser can cause injury to the skin and eyes from both the direct and scattered beams. It also presents a potential fire hazard. Safe use of the laser depends upon strict adherence of the following rules.

1. A register should be kept of all personnel authorized to operate the equipment and those personnel authorized to assist in the use of the equipment. One authorized operator shall be nominated by the Commanding Officer / Medical Officer in Charge to ensure that the register is maintained and to assume overall control of the installation and its safe operation.

2. It is the responsibility of staff authorized to be present during use of the laser to be aware of the nature of the hazard involved, to be familiar with the manufacturer's operating instructions and to ensure that the requirements for their own safety and for the patient's safety are being observed.

3. The operator is responsible for ensuring that persons assisting in the procedures are fully trained in the safe performance of their duties, and is responsible for the safety of any visitors who may be present.

4. The room in which the laser is used shall be designated a laser controlled area, when a laser is to be used. When the laser is in operation the number of persons in the room should be kept to a minimum. Spectators should not be allowed into the room unless supervisory approval has been obtained and appropriate measures taken.

5. All personnel (except the attending nurse, the operator and the patient) should keep behind the laser and well clear of the operator. All personnel must wear appropriate laser safety goggles, except the operator, who will be protected by the viewing microscope, and the patient. All protective eyewear should be labelled clearly with the optical density value, the wavelength(s) against which the protection is afforded and the maximum radiant exposure of the irradiance to which the eyewear may be exposed.

6. The laser shall not be switched on unless it is directed towards the patient's area of treatment, a suitable thermal barrier or a power-measuring instrument.

7. The following operating procedure shall be observed:

   a. Close the key switch and verify that the warning light outside the door is illuminated.

   b. Close the door.

   c. Carry out the manufacturer’s recommended TEST procedure.

   d. Adjust the microscope for treatment, then press the ON switch. Verify that the aiming beam is present. Set the desired power level.

   e. Select the mode of operation. Advise all present that treatment is about to start and then proceed using the footswitch.

   f. For a short pause in treatment, press the STANDBY switch to disable the footswitch.

   g. When treatment of a patient is completed, or a change of equipment is necessary, press the OFF switch.

   h. At the end of a session of operation, remove the key.

8. Whenever the equipment is unattended by an authorized operator, the control panel must be switched off and the key withdrawn and placed in safe custody by the authorized operator.

9. Operators must sign statements that they have read and understood these local rules. The completed statement will be held by the LSO.

Example of register of authorized personnel

Operators

Dr A
Dr B
Dr C

Manufacturer’s agent

Laser Safety Officer

Assistants

Custody of the key:

When not in use the key will be kept in the custody of:

____

The key will be clearly labelled with the words:

Laser to be used by authorized personnel only.

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LIST OF FIGURES

BIBLIOGRAPHY

Direct references

The following documents are referenced by this JSP:

BS EN 60825-1:1994 + Amendments 1, 2 & 3:2001	BS EN 60825-1:1994 Safety of Laser Products — Part I: Equipment. Classification, Requirements and User’s Guide incorporating its second amendment BS EN60825-1:1994 + Amendments 1, 2 & 3 2001
JSP 392	Instructions for Radiological Protection
BR 1043B	Gunnery and Guided Weapon User Instructions
BR 2	Queen’s Regulations for the Royal Navy — Chapter 51: Naval Casualty Procedures
STANAG 3606	Evaluation and Control of Laser Hazards on Military Ranges (Edition 5)
STANAG 2900	Laser Radiation — Medical Surveillance and Evaluation of Overexposure
Def Stan 00-55	Safety Critical Software
Def Stan 00-56	Hazard Analysis and Safety Classification of Defence Systems
DS & C	Health and Safety at Work, etc., Act 1974— Section 6
DS & C	Health and Safety Handbook, JSP 375
Dept of Health	Control of Substances Hazardous to Health Regulations (HMSO, ISBN 011 8336757)
Dept of Health	Guidance on the Safe Use of Lasers in Medical Practice (HMSO, ISBN 011 320857)
ISO 1000	SI Units and Recommendations for the Use of their Multiples and of Certain Other Units.

Other references

Other useful information may be found in the following documents:

ADFP 410	Defence Laser Safety (Australian)
ANSI Z136.1	American National Standard for the Safe Use of Lasers
ANSI Z136.2	American National Standard for the Safe Use of Optical Fiber Communication Systems utilizing Laser Diode and LED Sources
ANSI Z136.3	Safe Use of Lasers in Health Care Facilities
Army code 63723	Health & Safety Management in Equipment Support — Chapter 8
AS 2211	Laser Safety (Australian)
BS EN 207	Specification for Filters and Equipment used for Personal Eye-protection against Laser Radiation
BS EN 208	Specification for Personal Eye-protectors used for Adjustment Work on Lasers and Laser Systems
EN 60825-1:1994 +Amendments 1, 2 & 3:2001	EN 60825-1:1994 Safety of Laser Products — Part I: Equipment. Classification, Requirements and User's Guide incorporating its Amendments 1, 2 & 3 2001
JSP 403	Land Ranges Safety (UK)
STANAG 3828	Aircrew Protection against Laser Designators
STANAG 3830	Aircrew flash-blindness Protection
STANAG 3850	Categorization of Laser Designation Capability
STANAG 3875	Criteria for Categorization of Laser Designator Systems
STANAG 4401	Protection against Fixed-wavelength Battlefield Lasers
STANAG 4451	Protection against Battlefield Dazzle Lasers
USAF AFOSH STD 161-10	Health Hazards Control for Laser Radiation
US MIL-HDBK-828	Laser Range Safety (US)
US MIL-STD-882C	System Safety Program Requirements
US MIL-STD-1425A	Safety Design Requirements for Military Lasers and Associated Support Equipment

Relationship of laser Standards

A number of the above documents are inter-related. This relationship is illustrated in Fig. Bib-1 and is detailed in the paper Laser Safety Standards in Europe (J Laser AppI, 97–100, 6, (1994)).

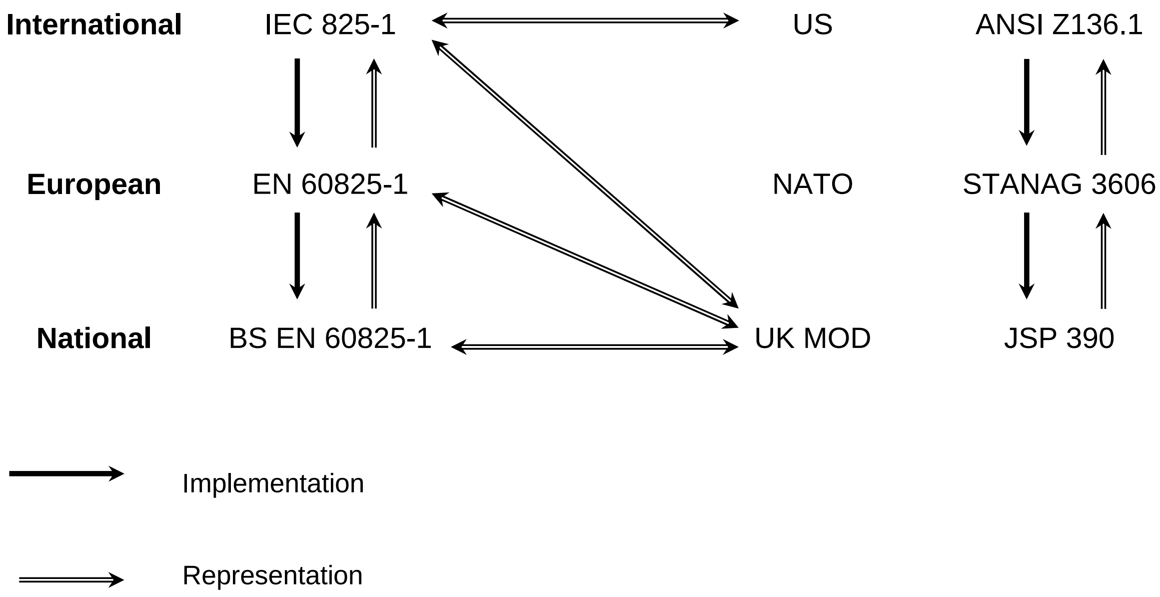

Fig. Bib-1 Laser Safety Standards

GLOSSARY 1 TERMS AND DEFINITIONS

The following terms and definitions are used in JSP 390:

Absorption.

Change of radiant energy to a modified form of energy (e.g. heat) by interaction with matter.

Accessible Emission limit (AEL).

The maximum accessible emission level permitted for a particular class of laser.

Actinic ultraviolet.

Ultraviolet radiation of wavelength between 180 nm and 315 nm.

Afterimage.

An impermanent effect which is produced in the visual field by a short, intense exposure to visible radiation, the characteristics of which may depend on the wavelength of the radiation.

Air-to-surface.

Describes firing activities from the air onto land, foreshore or sea.

Aperture.

Any opening in the protective housing, shielding or other enclosure of a laser product through which laser radiation is emitted, thereby allowing human access to such radiation.

Aqueous humour.

The clear, watery fluid which fills the front part of the eye.

Attenuation.

The decrease in laser intensity as it passes through an absorbing and/or scattering medium (e.g. the atmosphere).

Backstop.

Any natural or man-made obstacle used to terminate the laser beam and its associated buffer zone, both in azimuth and elevation.

Beam diameter.

The diameter of a laser beam at the exit aperture of a laser source or optical system expressed as the distance between the 1/*e*-points of the gaussian beam radiant intensity profile at right angles to the direction of propagation. It should be noted that most manufacturing data on beam divergence and output power or energy are with reference to $1/e^2$-points

Beam divergence.

The full angle of the beam spread expressed with reference to the 1/*e*-points of the gaussian beam radiant intensity profile.

Beam dump.

A device for absorbing laser energy at a specific wavelength.

Beam waist.

The smallest cross-sectional area of a laser beam. This is at its focus, which can be either inside or outside the laser system.

Blink reflex.

One of the eye's natural aversion responses to bright light.

Buffer zone.

Zone of exclusion of access to the laser beam.

Cavity resonator.

The optical enclosure within which coherent energy is built up and from which laser emission results. The emission is pulsed or continuous depending on the design and nature of the system.

Coherence.

Describes a state in which all the photons which are emitted from the source are in phase with each other, both in time and space, and are vibrating in the same plane. The resultant wave form is both temporally and spatially coherent along its direction of propagation. Typical of a laser.

Collimated beam.

Effectively, a nearly-parallel beam of light with very low beam divergence or convergence. A laser beam can be collimated much more effectively than other light beams since it is a coherent source.

Continuous wave (CW) laser.

A laser which operates with a continuous steady output for a period of greater than 0.25 seconds.

Cornea.

The transparent outer coat of the human eye that covers the iris and the crystalline lens. Along with the lens, it forms the main refracting element of the eye.

De-excitation.

Release of energy by an atomic system in the form of electromagnetic radiation.

Diffuse reflections.

An ideal diffuse reflection is one whose radiant intensity is independent of viewing angle.

Diode pumping.

A method of pumping a laser using diode lasers.

Dye laser.

A laser in which the active medium is liquid.

Electromagnetic radiation.

The flow of energy formed by orthogonally-vibrating electric and magnetic fields lying transverse to the direction of energy flow.

Electromagnetic spectrum.

The range of electromagnetic energy sources, including X-rays, ultraviolet radiation, visible light, infrared radiation and radio waves, all of which differ in frequency, wavelength and quantum energy.

Excitation.

The addition of energy to a system such as an atom, raising it above its lowest energy state.

Extended Nominal Ocular Hazard Distance (ENOHD).

The term used in the International Standards and British Standard for Extended Ocular Hazard Distance.

Extended Ocular Hazard Distance (EOHD).

The intrabeam safe viewing distance when magnifying optics are used.

Extended source.

Under certain conditions, the viewing of some laser diode arrays and diffuse reflections produces a retinal image size significantly larger than minimal and a more relaxed Maximum Permissible Exposure (MPE) may be applied.

Far-field.

The region in which the laser beam divergence can be treated as being constant.

Flashblindness.

An impermanent reduction or loss in vision which is produced by a short, intense exposure to visible radiation, similar to that produced by a flash lamp. An afterimage may follow.

Fluorescence radiation.

The visible radiation released by an atomic system when de-excited (see de-excitation).

Fovea.

The area on the retina which is responsible for all critical vision and colour discrimination. Whenever one looks directly at something, it is imaged onto the fovea.

Frequency doubling.

A nonlinear optical effect by which the laser frequency is convened to the second harmonic.

Gas laser.

A laser in which the active medium is a gas.

Gaussian beam.

A gaussian beam profile is one in which the intensity distribution is described by an exponential function about the peak value σ_0 given by:

$$\sigma = \sigma_0 \exp\left(-\frac{4\alpha^2}{\varphi^2}\right)$$

where α is the angle from the peak value and φ is the full angle of beam divergence (see Fig. 1-11).

Glare.

An impermanent ocular effect which is produced by scattering within the eye or by excess exposure to visible radiation (similar to that produced by the Sun).

Ground state energy.

The lowest energy state in an atom

Incoherence.

The opposite of coherence. Source emission is random and the emitted waves have no phase relationship. Typical of a non-laser source.

Injection laser.

A semiconductor or diode laser.

Integrated radiance.

The radiant energy emitted by an extended source into a solid angle of one steradian by one square metre of source. It is expressed in terms of J m^{-2} sr^{-1}.

Integrated radiant intensity.

The radiant energy in a given direction emitted per unit solid angle and is expressed in terms of J sr $^{-1}$.

Intra-beam viewing.

Refers to direct viewing along the laser beam towards the laser source.

Iris.

The circular pigmented membrane which lies behind the cornea of the eye. The iris is perforated by the pupil.

Irradiance.

The radiant power per unit area incident upon a surface and is expressed in W m^{-2}.

Lambertian surface.

An ideal surface where emitted or reflected radiance is independent of the viewing angle.

Such a surface is a perfectly diffuse reflector.

Laser.

An acronym for Light Amplification by Stimulated Emission of Radiation.

Laser Hazard Area (LHA).

The area bounded by the Laser Hazard Area Trace (LHAT) within which there is a risk of injury.

Laser pointer/pen.

A laser device used as an aid in audience presentations.

Laser Safely Clearance Certificate (LSCC).

A document authorizing laser operations.

Laser Safety Paper (LSP).

A document which defines the laser classification and laser hazards of an operational laser system, together with the procedures to be used for their control.

Lens.

An optical device which changes the divergence of a beam of light. In the human eye, the lens focuses the incoming light onto the retina.

Light amplification.

A process by which the intensity of light is increased. See resonant amplification and resonant cavity.

Light emitting diode (LED).

A semiconductor diode which emits optical radiation typically used for indicators, alphanumeric displays and remote control devices.

Liquid laser.

A laser in which the active medium is a liquid.

Log-normal distribution.

A random variable, Y, has a log-normal distribution if and only if $\log_e Y$ has a gaussian (normal) distribution.

Maximum Permissible Exposure (MPE).

The level of laser radiation to which a person may be exposed without suffering adverse health effects.

Meteorological range.

The horizontal distance at which the contrast transmission of the atmosphere is 2 per cent.

Minimum Ophthalmoscopically Visible Lesion (MOVL).

A 30 µm diameter retinal lesion that may be detected by using an ophthalmoscope.

Mode-locked laser.

A laser which produces very short pulses, very high peak powers.

Monochromatic.

Describes electromagnetic radiation having only one wavelength.

Near-field.

That region from the laser exit aperture along which the laser beam is almost parallel.

Nominal Ocular Hazard Distance (NOHD).

The distance along the axis of the beam from the laser beyond which the irradiance or radiant exposure would not be expected to exceed the MPE for the unaided eye. This assumes a gaussian beam profile and takes no account of atmospheric effects.

Non-ionizing.

Describes radiation which, when interacting with the atoms of a material, does not cause ejection of electrons which would result in the atoms becoming electrically charged. Laser radiation is an example.

Nonlinear optics.

The interaction of optical radiation with materials in which a nonlinear response occurs, resulting in an intensity-dependent variation of characteristics (e.g. thermal effects).

Ocular Hazard Distance (OHD).

The safe viewing distance in an actual case, taking into account all the corrections that need to be applied to the NOHD.

Optical density (OD).

The logarithm, to base 10, of the inverse of the transmittance at a specific wavelength.

Optical energy.

Energy in the form of light.

Optical phase conjugation.

A state where waves have equal but opposite phases.

Optical resonator.

The device which produces laser light.

Optic nerve.

The sensory nerve of each eye that connects the retina to the brain.

Orbiting electron.

The structure of the atom is a central nucleus around which electrons orbit (c.f planets around the Sun).

Phase relationship.

Refers to the state of the waveforms of a laser beam.

Photochemistry.

The study of the chemical effects of radiation, chiefly visible and ultraviolet.

Photon.

A quantum or packet of electromagnetic wave energy.

Plane of polarization.

The plane of vibration of the laser wave form.

P-n junction diode.

The boundary between p-type and n-type semiconductor material. P-type material is deficient in electrons, while n-type material has excessive electrons.

Point source.

For intrabeam viewing a laser effectively acts as a point source. Direct ocular exposure to a highly-collimated beam of laser radiation effectively produces a diffraction-limited point image on the retina, which will result in the highest level of irradiance or radiant exposure on the retina for a given radiant power or energy.

Population inversion.

A condition of the two atomic states which are responsible for the laser transition, where the population of electrons in the higher state exceeds that of the lower state, contrary to the natural order.

Probabilistic ‘catastrophe’.

A situation in which either a probabilistically-modelled event occurs with unit probability, or a probabilistically-defined parameter takes some specific value with unit probability.

Probabilistic laser safety scenario.

A laser safety scenario in which the chance of ocular irradiation is very small, and in which the major elements under consideration are inherently probabilistic.

Propagation.

The passage of electromagnetic energy through a medium (usually, the atmosphere).

Protected firing.

A laser firing in which the laser beam is wholly contained and terminated by a mechanical device or absorbent material.

Protection Standard (PS).

The STANAG 3606 equivalent of MPE.

Pulse length.

The time between the rising and falling edges of a pulse referenced to the half of peak power points.

Pulse repetition frequency (PRF).

The number of pulses fired per second. It is expressed in units of Hz.

Pulsed laser.

A laser which delivers its energy in the form of a single pulse or a train of pulses, where the duration of a pulse is less than 0.25 s.

Pumping.

The process which achieves a state of population inversion.

Pupil.

The variable aperture in the iris through which light travels toward the interior region of the eye.

Q-switch.

A device for producing very short intense pulses. Hence a Q-switched laser emits short high-power pulses.

Quantum theory.

The theory of photon interaction with materials and the foundation of many optical devices, including lasers, image intensifiers and thermal imagers.

Radiance.

The radiant power emitted by an extended source into a solid angle of one steradian by one square metre of the source. It is expressed in terms of $W\ m^{-2}\ sr^{-1}$.

Radiant energy.

The output of a pulsed laser and is expressed in joules.

Radiant exposure.

The radiant energy per unit area incident upon a surface and is expressed in $J\ m^{-2}$.

Radiant intensity.

The radiant power in a given direction emitted per unit solid angle and is expressed in terms of $W\ sr^{-1}$.

Radiant power.

The output of a continuous wave laser and is expressed in watts.

Radiation.

A general term to describe the emanation of different forms of energy (e.g. electromagnetic, nuclear, acoustic).

Raman shifting.

A process by which the frequency of electromagnetic radiation can be changed, usually increased, by interaction with specific materials.

Rayleigh length.

The length along the laser beam axis of a laser, operating in TEM_{00} mode of oscillation, at which the beam cross-sectional area is twice that of the area at the beam waist.

Rayleigh scattering

Scattering of radiation in the course of its passage through a medium containing particles the sizes of which are small compared with the wavelength of the radiation.

Refractive index.

The ratio of the speed of light in a vacuum to that in a medium through which it travels.

Resonant amplification.

The process by which the laser intensity builds up in the resonator cavity.

Resonant cavity.

The optical enclosure within which coherent energy is built up and from which laser emission results.

Retina.

The sensory membrane that receives the incident image formed by the cornea and lens of the eye. The retina lines the posterior portion of the eye.

Retro reflection.

A beam reflected back directly towards the source.

Scattering.

A process which reduces laser intensity by interaction with atoms and molecules.

Scenario event.

Any single occasion on which a laser is used for its designated purpose.

Scintillation.

Rapid changes in irradiance levels in a cross-section of a laser beam caused by atmospheric turbulence, sometimes referred to as hot spots.

Semiconductor laser.

A laser in which the laser medium is a p-type or n-type semiconductor diode, e.g. gallium arsenide.

Solid-state laser.

A laser which uses laser-active atoms or ions embedded in a host material which itself is transparent to the laser wavelength.

Spatially coherent.

Describes light in which all the emitted waves are in phase with each other. Typical of a laser.

Spectral emission.

The emission of light containing many wavelengths.

Specular reflection.

A mirror-like reflection.

Spontaneous emission.

The process by which an atom in a higher atomic state naturally decays spontaneously to a lower atomic state.

Stimulated emission.

A process whereby a light photon of energy exactly equal to the energy difference between the two atomic states taking part in the laser action causes an atom in the higher state to de-excite to the lower state. This produces a further photon which is exactly coherent with the existing photon and thus produces amplification.

Temporally coherent.

Describes light of very narrow bandwidth (i.e. monochromatic).

TEM_{00} oscillation.

The lowest order or fundamental mode of oscillation in an oscillator.

Thermal blooming.

The heating of the atmosphere at the focus of a high-energy convergent laser beam.

Transmittance or transmissivity.

The ratio of total transmitted energy (power) to the total incident energy (power) at a specific wavelength.

Units.

These should be in accordance with the *Système Internationale d'Unités* (SI) and the *Commission Internationale d'Eclairage* (CIE) standard nomenclature.

The SI units used in this JSP (and their symbols) are:

Quantity	*Unit*	*Symbol*
Length	metre	m
Time	second	s
Plane angle	radian	rad
Solid angle	steradian	sr
Frequency	hertz	Hz
Energy	joule	J
Power	watt	W

Additionally, the plane angle unit of the degree (°) may be used ($1° = \pi/180$ rad).

Prefixes may be used to express multiples and parts of these units. The prefixes used in this JSP, or which may be encountered in similar laser safety documentation (see Bibliography), are:

E (exa)	10^{15}
T (tera)	10^{12}
G (giga)	10^{9}
M (mega)	10^{6}
k (kilo)	10^{3}
d (deci)	10^{-1}
m (milli)	10^{-3}
μ (micro)	10^{-6}
n (nano)	10^{-9}
p (pico)	10^{-12}
f (femto)	10^{-15}

Further information on the use of SI units can be found in ISO 1000.

Unprotected firing.

A laser firing in which the laser beam traverses free space, before being terminated by a mechanical device or other suitable backstop.

Vitreous humour.

The transparent, colourless mass of soft, gelatinous material filling the eyeball behind the lens.

Wavelength.

Distance between adjacent wavefronts and equal to the speed of light (in metres per second) divided by the frequency (in hertz).

Wet target reflection.

The condition describing reflection from a wet surface. The reflected beam divergence lies between specular and diffuse reflection cases, and experimental data shows a worst-case wet surface increases the laser beam divergence by at least 2.5 mrad.

GLOSSARY 2 MATHEMATICAL SYMBOLS

a	Emergent laser beam diameter at the 1/e-peak of irradiance or radiant exposure points (m).
a_x, a_y	Laser beam diameters across major and minor axes of an elliptical, otherwise gaussian, laser beam (m).
A	A factor in the determination of the attenuation coefficient.
A	Semi-angle of azimuth mechanical laser pointing limits (rad).
A_R	Area of a diffuse surface intersected by a laser beam (m^2).
$C_1,\ldots,C_7$	Correction factors in the determination of the MPE. C_5 is the multiple-pulse correction factor. C_6 is the extended-source correction factor.
C_n	Atmospheric refractive index structure factor ($m^{-1/3}$).
C_{n1}	Atmospheric refractive index structure factor at one metre above the ground ($m^{-1/3}$).
C_{nh}	Atmospheric refractive index structure factor at height h above the ground ($m^{-1/3}$).
d	Laser beam diameter at the 1/e -peak of irradiance or radiant exposure points (m).
d_0	Value of d at the laser beam waist (m).
D_0	Diameter of the objective lens of magnifying optics (m).
e	Base of Napierian logarithms (2.718...).
e_{OD}	Expectation of an eye sustaining ocular damage due to accidental irradiation by a single pulse/burst of laser energy.

$e_{\mathrm{OD/FF}}$	That part of e_{OD} which arises from fault-free operation of the laser directional system.
$e_{\mathrm{OD/F}}$	That part of e_{OD} which arises from the occurrence of a fault in the laser directional control system.
E	Irradiance (W m^{-2}).
E_0	Emergent laser beam irradiance (W m^{-2}).
E_m	The applicable protection standard or MPE for CW radiation (W m^{-2}).
E_{MOVL}	Expectation of an irradiated eye sustaining ocular damage at the MOVL level.
E_{OD}	Overall expectation of ocular damage for a single scenario event.
$E_{\mathrm{OD/FF}}$	That part of E_{OD} which arises from fault-free operation of the laser directional system.
$E_{\mathrm{OD/F}}$	That part of E_{OD} which arises from the occurrence of a fault in the laser directional control system.
E_{ODMAX}	Maximum ‘acceptable’ value of E_{OD} defined by the MLSC for a specific probabilistic model.
EOHD	*NOHD* corrected for the use of magnifying optics (Extended Ocular Hazard Distance), sometimes known as *ENOHD*.
E_R	Irradiance of a non-diverging beam at range R (W m^{-2}).
F	Fresnel number = $\frac{\pi a^2}{2\lambda_1 R}$
g	Diameter of the pupil of the dark-adapted eye (7×10^{-3} m).

g_S	Multiplicative gain in irradiance or radiant exposure due to atmospheric scintillation.
H	Radiant exposure (J m^{-2}).
H_m	The applicable protection standard or MPE for pulsed radiation (J m^{-2}).
I_P	Peak radiant intensity (W sr^{-1}).
I_Q	Peak integrated radiant intensity (J sr^{-1}).
K	Hazard gain factor of an optical instrument.
M	Magnifying power of an optical instrument.
M_0	Beam expansion factor of a laser system’s optics.
MPE	Maximum Permissible Exposure.
N	Number of pulses in a pulse train.
N_1	NOHD or OHD taking into account the full or partial consideration of magnifying optics, beam-attenuating filters, laser protective eyewear, atmospheric effects and near-field effects as appropriate (m).
$N_{\max}$	Distance at which atmospheric scintillation maximizes (m).
NOHD	Nominal Ocular Hazard Distance (m).
OD	Optical density of a filter.
OHD	The safe viewing distance (Ocular Hazard Distance) in an actual case, taking into account all the corrections that need to be applied to the NOHD (m).

OHD_A	OHD allowing for magnifying optics, beam-attenuating filters, laser protective eyewear, atmospheric scintillation, near-field effects and atmospheric attenuation (m).
OHD_F	OHD allowing for magnifying optics and beam-attenuating (m).
OHD_P	OHD allowing for magnifying optics, beam-attenuating filters and laser protective eyewear (m).
OHD_N	OHD allowing for magnifying optics, beam-attenuating filters, laser protective eyewear, atmospheric scintillation and near-field effects (m).
OHD_S	OHD allowing for magnifying optics, beam-attenuating filters, laser protective eyewear and atmospheric scintillation (m).
OHD_R	OHD from a reflector (m).
P	Radiant power (W).
$P_{E/F}$	Probability of pointing in a given direction as a result of a fault in the laser directional system.
$P_{E/FF}$	Probability of pointing in a given direction during fault-free operation of the laser directional system.
P_F	Probability of a fault in the laser directional system.
$P_{I/F}$	Probability of irradiating a person as a result of a fault in the laser directional system.
$P_{I/FF}$	Probability of irradiating a person during fault-free operation of the laser directional system.
$P_I\,(X)$	Probability of irradiating a point X.

$P_{\mathrm{OD}}(H)$	Probability of receiving ocular damage if irradiated with energy of radiant exposure H.
$P_S(g_S)$	Probability density function for the multiplicative gain, g_S, in irradiance or radiant exposure, at a given point, due to atmospheric scintillation.
Q	Radiant energy (J).
R	Range from a laser to a target or observer (m).
R_1	Maximum range at which extended-source criteria apply (m).
R_N	Rayleigh length of a laser (m).
S_E	Standard deviation of elevation pointing errors (rad).
T	Pulse train duration (s).
T_1, T_2	Time factors used in the determination of the MPE (s).
U	Incident irradiance (W m^{-2}) or radiant exposure (J m^{-2}).
U_0	Laser intensity transmitted by protective eyewear.
V	Meteorological range (m).
X	A general point on land, sea or in the air, where an unprotected or unwarned person could suffer irradiation by laser energy.
Z_1, Z_2, Z_3	Factors used in the determination of OHD_r.

α (alpha)	Angle subtended by a laser source (rad).
α_{min}	Limiting value between a point-source and extended-source viewing (1.5×10^{-3} rad)
α_{max}	Maximum value of a considered (100×10^{-3} rad)
α_X	Azimuth angle of a point X relative to a target position (rad).
ε_T	Elevation angle of a target position relative to the local horizontal (rad).
ε_X	Elevation angle of a point X relative to the local horizontal (rad).
η	Standard deviation of log-irradiance.
θ	Angle between the normal of a reflecting surface and the viewing direction (deg or rad).
λ	Wavelength (nm).
λ_1	Wavelength (m).
μ	Atmospheric attenuation coefficient (m’) at a given wavelength.
ν	Refractive index.
π	Ratio of a circle’s circumference to its diameter (3.141...).
ρ_d	Coefficient of diffuse reflection.
ρ_i	Coefficient of internal reflection of glass.
ρ_S	Coefficient of specular reflection.

σ_{pa}	Peak-to-average ratio of a laser beam profile (average taken over the circle containing 90% of total energy).
τ	Transmittance of an optical system at the laser wavelength.
φ	Laser beam divergence at the $1/e$-peak of irradiance or radiant exposure points for assumed gaussian beams (m).
φ_1	Additional beam divergence as a result of a wet target reflection (2.5×10^{-3} rad).
φ_x, φ_y	Laser beam divergences across major and minor axes of an elliptical, otherwise gaussian, laser beam (rad).
ψ	Angle of incidence of a laser beam to a reflecting surface (deg or rad).
ψ_r	Angle of refraction (deg or rad).
$<$	Less than.
$\leq$	Less than or equal to.
$>$	Greater than.
$\geq$	Greater than or equal to.

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GLOSSARY 3 ABBREVIATIONS AND ACRONYMS

ACOS(M&D)	Assistant Chief of Staff (Medical and Dental)
AEL	Accessible Emission Limit
Al_2BeO_4	Alexandrite chrysoberyl
ALR	Airborne laser rangefinder
AWC	Air Warfare Centre
BS	British Standard
CCTV	Closed circuit television
CHS	Centre for Human Sciences
CIE	Commission Internationale d'Eclairage (International Commission on Illumination)
CLSO	Command Laser Safety Officer
CMT	College of Management and Technology
CO	Commanding Officer
CO_2	Carbon dioxide
COSHH	Control of Substances Hazardous to Health
CPS	Cardinal Points Specification
Cr^{3+}	Chromium (triply-charged)
CW	Continuous wave
DAUK	The Defence Academy of the United Kingdom
DC	Direct current
DESB	Defence Environment and Safety Board
DF	Deuterium fluoride
DFWES	Direct Fire Weapon Effects Simulator
DLO	Defence Logistics Organisation
DLRSC	Defence Land Ranges Safety Committee
DLSO	Divisional Laser Safety Officer
DMO	Director of Military Operations
DMSO	Dimethyl sulphoxide
DNO	Director of Naval Operations
DOSB	Defence Ordnance Safety Board
DOSG	Defence Ordnance Safety Group
DPA	Defence Procurement Agency
DRPS	DSTL Radiological Protection Service
DS & C	Directorate of Safety, Environment and Fire Policy
DSTL	Defence Science & Technology Labs.
EMC	Electromagnetic compatibility
EN	Euronorm

ENOHD	Extended Nominal Ocular Hazard Distance
EOHD	Extended Ocular Hazard Distance
Er:YLF	Erbium yttrium lithium fluoride
ESO	Establishment Safety Officer
FFHAT	Fault-Free Hazard Area Trace
FHAT	Fault Hazard Area Trace
FLFP	First Laser Firing Point
FMEA	Failure mode effects analysis
GaAs	Gallium arsenide
GPEOD	General Purpose Electro-Optical Director
HCL	Hydrogen chloride
HeNe	Helium-neon
HF	Hydrogen fluoride
Ho:YAG	Holmium yttrium aluminium garnet
Ho:YLF	Holmium yttrium lithium fluoride
HR	Human resources
HSW Act	Health and Safety at Work, etc., Act, 1974
IEC	International Electrotechnical Commission
IR	Infrared
JSP	Joint Services Publication
KrF	Krypton fluoride
Ladar	Laser detection and ranging (laser radar)
Laser	Light amplification by stimulated emission of radiation
LED	Light emitting diode
LFHA	Laser Fault Hazard Area
LHA	Laser Hazard Area
LHAT	Laser Hazard Area Trace
$LHAT_D$	Laser Hazard Area Trace (Deterministic)
LLFP	Last Laser Firing Point
LP6/7	Laser Projector 6/7
LRMTS	Laser Ranger and Marked Target Seeker
LSCC	Laser Safety Clearance Certificate
LSO	Laser Safety Officer
LSP	Laser Safety Paper
LSRP	Laser Safety Review Panel
LTM	Laser Target Marker
Maser	Microwave amplification by stimulated emission of radiation
MLSC	Military Laser Safety Committee
MOD	Ministry of Defence

MOVL	Minimum Ophthalmoscopically Visible Lesion
MPE	Maximum Permissible Exposure
NATO	North Atlantic Treaty Organization
Nd:YAG	Neodymium yttrium aluminium garnet
NOHD	Nominal Ocular Hazard Distance
OD	Optical density
OHD	Ocular Hazard Distance
OME	Ordnance Munitions and Explosives
OSRP	Ordnance Safety Review Panel
PRF	Pulse repetition frequency
RAF	Royal Air Force
REP	Repetitively-pulsed
RF	Radio frequency
RSO	Range Safety Officer
SI	Système International d'Unités
SNCO	Senior Non-Commissioned Officer
SOP	Standard operating procedures
SP	Single-pulsed
SR LHAT	Specular Reflector Laser Hazard Area Trace
STANAG	Standardization Agreement
TEA	Transversely excited atmospheric
TEM	Transverse electromagnetic
TIALD	Thermal Imaging (& TV) Airborne Laser Designator
TLS	Tank Laser Sight
UK	United Kingdom
UV	Ultraviolet
WT LHAT	Wet Target Laser Hazard Area Trace
XeCl	Xenon chloride

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