2. Literature Review

2.1 Introduction

As has already been stated in the Introduction, the laser is approaching forty years of age and has been used in entertainment for almost as long. It would be reasonable to expect that guidance, either official or from the industry, would be available to address the safety issues. In practice, the guidance is limited. This chapter reviews the implications of guidance which is available, how these have built on formal standards, and the legal issues in the UK and elsewhere. Of particular concern is how any published material assists those staging laser events, those who promote or host such events, and the enforcing authorities to assess the risks from the use of lasers.

2.2 Laser Entertainment Guidance

There are few specific guidance documents relating to the use of lasers in the entertainment industry. UK guidance is described in this section along with guidance from elsewhere in the world.

2.2.1 Guidance Note PM19

The official guidance on the use of lasers in the entertainment industry in the UK until October 1996 was PM19, published by the Health and Safety Executive in December 1980 (HSE 1980). Since this document was published about seven years after the first laser show in the UK it would be reasonable to expect it to have addressed many of the safety issues. That the document remained the only formal guidance document for sixteen years would also suggest that it must have been successful.

Many of the guidelines in PM19 are derived from statements made by the US Bureau of Radiological Health in 1977 and 1978 (Sliney and Wolbarsht 1980). These statements required that anyone putting on a laser display should be considered a manufacturer of a laser product. The US Federal Product Compliance Standard, 21CFR1040.10 (FDA 1976), required that only class I or class II laser products may be sold as "demonstration laser products". In order to use a laser product of a higher laser class, it was necessary to have a "variance" from the requirements of 21CFR1040.10 having met a number of criteria. These criteria were transferred to the requirements of PM19 and include a requirement for the accessible emission limit for class I (termed class 1 in PM19) not to be exceeded where the audience is to be seated or standing. Separations of 3 m vertical and 2.5 m laterally also come from the US guidance, for supervised performances.

The most important part of PM19 is the requirement for the operator of any display laser product to provide health and safety enforcement officers with "sufficient information, sketches, calculations, radiometric measurement data, etc, to demonstrate that the system can be used safely and without risks to health". This shows that the requirement for a risk assessment has existed in UK guidance since 1980. Irrespective of the content of the remainder of the guidance, this should have provided clear guidance of what was required to meet the general requirement for risk assessment under the Health and Safety at Work etc Act 1974 (HMSO 1974) and the later Management of Health and Safety at Work Regulations 1992 (HMSO 1992).

Another key to the pedigree of PM19 is the reference to the US ANSI Standard Z136.1 (ANSI 1976) for maximum permissible exposure (MPE) and accessible emission limit values. The laser classification scheme was not introduced into the UK until the adoption of the British Standard BS 4803: 1983 (BSI 1983). However, the ANSI standard was updated in 1979 and it introduced further guidance on laser displays, including guidance on the time base to be used. This is still contained in the current ANSI Standard (ANSI 1993), which states in 4.5.1 that "the applicable MPE may be determined by using the classification duration

defined as the total combined operational time of the laser during the performance or demonstration within any single period of 3×10^4 seconds".

The failings with PM19 are generally through omission. It appears to be assumed that laser radiation will not be scanned across the faces of members of the audience, so-called audience scanning. At least there is no indication of how such an assessment should be carried out. A strict application of the guidance given would be that a scanned beam should be analysed on a single pass of the beam across the eye, with no account taken of repeated exposures.

Appendix 3 of PM19 provides a suggested proforma for presenting the necessary information to the enforcing officer. These tended to be completed by laser display companies to varying degrees, but most followed a generic pattern, thought to originate from one or two longer standing laser display companies. At the start of this research it was considered that the information supplied was too generic to be meaningful. However, it was recognised that an enforcing officer presented with the minimum information may consider the information was meaningful without fully understanding the technical and safety issues. Viewing one Appendix 3 proforma in isolation would not easily identify the lack of specific information about a particular event.

PM19 only covers laser radiation. The other safety aspects, such as fire, explosion, electric shock, etc, are only mentioned in passing in the introduction.

2.2.2 Guidance Note HS(G)95

PM19 was replaced by a further publication from the Health and Safety Executive in October 1996, HS(G)95 (HSE 1996a). This document is specifically titled to only include laser radiation. HS(G)95 is intended to be a goal-setting document with little specific guidance on how to achieve these goals, as is the current climate of UK legislation and guidance. The guidance again stresses the need for risk assessment and clearly sets down the requirements for this through from the designer of the equipment to the laser operator.

Examples of equipment are given in HS(G)95 to illustrate specific points. However, some of these have not been thought through. For example, an example of an external optical component is given as a mirror mounted on a wall bracket using a ball joint. Such devices are generally subject to severe vibration and most products would now be expected to have no vertical movement by design such that the mirror mount, even if it becomes loose, does not tilt the beam down into the audience.

The guidance is now set in terms of maximum permissible exposure only, which is more logical, rather than referring to the classification of the laser display.

Audience scanning is considered, and recognised as a high risk activity by the requirement to have supervision. Chapter 4 of the guidance considers an Installation Safety Assessment. Several pages are dedicated to the issue of audience scanning, although there is no practical guidance on how to actually carry out the assessment. A lot of emphasis is placed on scan failure systems. An interesting footnote at the bottom of page 8 states "HSE recognises that measurement down to the applicable MPE and of scanned emissions may be impracticable". This demonstrates a complete lack of understanding of the measurement issues and the technology available to undertake the assessments.

There are a number of questions which need to be asked about this replacement to PM19. Is it better? In many ways it is, because it does include some more background information, but that does not mean it is more helpful for either the laser company or the enforcing officer. Discussions with both parties suggested that they preferred specific guidance so that a consistent level of enforcement could be expected across the UK. Does it provide practical guidance on risk assessment? No, it gives some pointers but again no practical

guidance. Probably the most significant omission from HS(G)95 compared with PM19 is the requirement to notify the enforcing authority. In an ideal world, with self regulation of the industry, this would not be necessary. However, an indication that such notifications are not necessary may mean that laser displays may take place without the necessary safety management and control needed to ensure that they are carried out with the minimum of risk to the public.

2.2.3 Non-UK Guidance

There are a small number of guidance documents issued by other countries. Laser Light Show Safety - Who's Responsible (FDA 1986) published by the Food and Drug Administration (FDA) in the US provides some background information on lasers and hazards, but only mentions the laser radiation hazard. It covers the Government requirements, mainly in terms of requiring a variance from the FDA to operate laser displays. Mention is made of possible additional State and local requirements. There is nothing in the document to explain what a laser show is, nor is audience scanning covered.

The FDA have also issued a number of documents aimed specifically at their inspectors. Examples include the Compliance Guide for Laser Products (FDA 1985) and the Analysis of Some Laser Light Show Effects for Classification Purposes (FDA 1979). Appendix B of the former document includes a statement on Clarification of Certain Laser Light Show Requirements. This includes audience scanning and scanning safeguards. The statement recognises that scanned laser radiation with a peak power in excess of 5 mW has an acute risk of injury if it were to slow down or stop. No account appears to be taken of the effect of multiple pulses as the laser radiation is scanned. Scanning safeguards are considered a "critical performance feature" for high power laser shows. The statement does recognise that, at the time of issue, the FDA had "not received data to show that any scanning safeguard system is adequate for audience scanning".

The second document includes a number of calculations of laser light show effects using galvanometer scanning systems. It includes sawtooth, triangular and sine wave drive signals, all generated from analogue sources. The assessments consider time bases for the duration of example effects and compare the energy into a 7 mm aperture with class I accessible emission limits. However, no consideration is taken of multiple pulses as the beam is repeatedly scanned across the eye.

On 13 December 1979, the Health Protection Branch of the Health and Welfare Canada issued guidance (Morrison 1979) which appears to be based on the FDA recommendations of 1978, and therefore is similar to PM19.

The National Health and Medical Research Council of Australia issued a Code of Practice for the Safe Use of Lasers in the Entertainment Industry in 1995 (NHMRC 1995). This is one of a pair of documents published at the same time, the other one covering the use of lasers in schools. The approach taken in the two documents is similar, even though the intended targets are so different. The Code of Practice only considers the laser radiation issues, although the reader is referred to other Australian documents for cryogenic coolant and high voltage safety. Annexe B provides a flowchart for the recommended alignment procedure. The procedure described suggest that the author has little or no practical experience of a laser light show installation, being more appropriate for a laboratory environment than an entertainment venue. Annexe C recommends a proforma for a Display Safety Record. This requires an assessment of the hazards but does not consider the risks having assessed the hazards.

2.2.4 Summary of Entertainment Laser Guidance

The number of documents available for specific guidance on the safe use of entertainment lasers is small. All concentrate on the laser radiation aspects, with no guidance on non-radiation hazards. Although a requirement for risk assessment was included in the 1980 UK guidance (PM19) this has not been practically addressed.

There is clearly the potential for conflict between laser display companies and enforcing officers where guidance, such as HS(G)95, uses a goal-setting approach. The means for achieving the goals rely on an understanding of both the laser safety issues and the practical aspects of laser displays.

Most other countries appear to have no guidance on the safe use of laser displays. Only the US, Canada and Australia have issued guidance. These all suffer the same deficiencies as the UK guidance.

2.3 General Entertainment Guidance

If no practical specific guidance is available for laser display companies then there may be general guidance aimed at the entertainment industry which fills the gap. This is reviewed for the UK. The documents include formal guidance from government, professional association guides and books aimed at the industry.

2.3.1 Fire Precautions Guide

In 1990 the Home Office/Scottish Office published a guide covering fire precautions in entertainment venues which was revised in 1994 (HMSO 1994a). Lasers are covered in three paragraphs (11.40 to 11.42). The first paragraph introduces the laser and the hazard potential. The second paragraph states that certain lasers can present a fire risk and states that licensees should ensure that lasers should be installed and operated by experts although it does not give any guidance to the licensee on how he is to determine the level of expertise. The final paragraph refers to PM 19 and BS 4803: Part 3 (assumed to be the 1983 edition). The publication of a revised standard, BS 7192: 1989 (BSI 1989), was not considered when the document was revised for publication in 1994. However, the Introduction states that the current version of any British Standard should be used.

The guide has no statutory force but it does state (paragraph 6.51) that no lasers should be installed or used without approval. This approval is defined as approval in writing by the licensing authority. An obvious omission is that the guide does not define what the licence is for. It can be assumed that the reference is to the entertainment licence. The legislation concerning entertainment licensing will be considered later.

2.3.2 Pop Concerts Guide

The Health and Safety Commission, the Home Office and the Scottish Office jointly published a guide which has become known as either the Pop Guide or the Purple Guide on account of the colour of its cover (HMSO 1993). The guide has a very practical approach to the safety aspects of events involving large groups of people. It covers management and planning of events, two aspects that do not appear to feature highly in many events involving lasers.

Appendix 1 covers the legal aspects of putting on a pop concert. Three paragraphs are devoted to the legal requirement to undertake a risk assessment and a degree of practical guidance is provided. This is a six step process which covers identifying the hazards through to safe systems of work and review. However, the guidance is not detailed enough for anyone needing to carry out a risk assessment for the first time and by hiding the requirement in an appendix, the implication is that such as assessment is not part of the main management function.

Chapter 10 of the guide covers special effects and pyrotechnics and includes lasers. Reference is made to the then guidance, PM19 and the expected revision HS(G)95.

The requirement for a laser safety officer (LSO) is discussed in paragraphs 10.6 and 10.7. The code suggests that the LSO could be an external consultant. Handover documents are mentioned in 10.7 and 10.8. The closest that laser companies normally get to these are the appendix 3 forms from PM 19. Paragraph 10.8

suggests that the handover document “should contain a detailed specification of the intended scope of the display and the operator should not deviate from that specification. The document should be specific to the venue where the laser display is to occur and should include a drawing of the laser display area in both plan and elevation. The positions of laser sources, mirrors and target areas should be clearly marked, along with the relevant distances and dimensions. The licensing authority will normally ask to see a copy of the handover documents”. The onus appears to be placed on the licensing authority to ask for any documentation relating to the laser display, rather than such information being provided up front as required by PM19, and perhaps represents the views of the Health and Safety Executive which were eventually introduced into HS(G)95. Documentation as specific as that suggested here is extremely rare, even for permanent laser installations.

2.3.3 National Outdoor Events Association

The National Outdoor Events Association (NOEA) have published a comprehensive code of practice covering many aspects of outdoor events "other than Pop Concerts and Raves" (NOEA 1993). Members of NOEA are expected to comply with the code of practice but it is also intended for “Organisers (who will know what they can expect to receive), the Suppliers (who will know what they are expected to provide), Inspecting Officers (who will receive clear guide lines and check lists) and all members of the trade associations connected with the Industry (who will then monitor the performance of its members in these activities)”.

This code starts with risk assessment and provides suggestions for categories for hazard, risk potential, event type and attendance group. However, the code does recognise that simple assignment of numbers to each of these categories may not be adequate and full detailed assessments may need to be carried out to satisfy all legal requirements.

Laser are defined as “high intensity lighting or strobes arranged for displays”. The section on lasers comes within the Electrical chapter. It is interesting that the electrical hazards are considered first. The code requires the installation to be carried out by a “competent engineer skilled in this particular field of operations”. The code goes on to say there may “exist non-electrical risks such as radiation or the induction of epilepsy from such equipment”. The code refers to PM 19 and to a loose-leaf annexe accompanying the code. The description of the laser classification system is misleading: particularly classes 3A and 3B appear to have been combined into one class and the description is more appropriate to class 3A. The annex refers to BS 7192: 1989 (BSI 1989), although BS EN 60825: 1992 (BSI 1992) was available at the time of publication.

2.3.4 Institute of Lighting Engineers

The Institution of Lighting Engineers (ILE) produced a code in 1995 which included lasers (ILE 1995). The code was produced by a panel with major input from one of the laser display companies. As such, much of the organisational and technical content is quite good. However, there are some basic misunderstandings of the real personnel exposure situations and the risks involved. In particular, the document considers that calculations in support of risk assessments are inaccurate and should only be used when measurements are not possible. However, there is no specific guidance on how the measurements should be carried out. A worrying suggestion is that laser power meters should be used. It is unlikely that these would respond correctly to a scanned laser beam.

2.3.5 Focal Guide

The Focal Guide to Safety in Live Performances (Thompson 1993) considers many safety issues relating to events where lasers are likely to be used. Although the book starts with a chapter on “Safety, Risk and Hazard” this is not followed through into practical guidance. Advice is presented on the associated hazards from laser events, such as staging, electricity, fire, smoke machines and audience management. A chapter is

dedicated to lasers which includes a cursory introduction to laser entertainment technology. When considering the safety evaluation of scanned laser effects, it is assumed that high speed scanning is acceptable for high power lasers provided adequate scan-fail detection and control systems are incorporated. No account appears to be taken of the multiple exposure situation under such scanning conditions. Laser classification is described and it is difficult to see what this achieves since most lasers used in the entertainment industry have the potential to cause eye injuries, ie they are class 3B or class 4. It would have been more appropriate to consider the maximum permissible exposure alone.

2.3.6 Summary of General Entertainment Guidance

The official and industry general guides to safety in the entertainment industry address many of the issues which are common, such as management and planning. However, risk assessment, although introduced is not covered in any detail. Lasers are introduced in each of the guides but generally reference is made to the specific UK laser guidance documents. The advantage of these broader guides is that they address many of the safety issues associated with the use of lasers which are not covered in the specific laser guidance, such as electricity, fire and manual handling. However, the practical guidance on risk assessment appears to be no further developed for these sections of the industry than it is for the laser radiation.

2.4 Laser Safety Standards

Reference has been made to the accessible emission limits and maximum permissible exposure (MPE) levels for laser radiation. These are tabulated in Standards. The MPE levels are derived from experimental data, essentially comparing the effect on the eye or skin with various quantities of laser radiation incident on the respective organ. Some data also comes from incidents involving accidental exposure of people to laser radiation.

The first fully reported laser injury occurred in February 1964 (Rathkey, 1965) when a student in Oregan, USA, received an eye exposure from a ruby laser pumped with an argon flash lamp. However, the biological research into potential eye injuries had been started some years earlier. Zaret *et al* (1961) reported experimental results on 'optical maser' exposures of rabbit eyes in 1961. The radiant exposure levels used for the experiments was 2×10^4 greater than the current value for the maximum permissible exposure (BSI, 1994). The authors compared the results with effects produced after exposure to the optical radiation from atomic bomb explosions.

Laser Focus World published an account by Decker (1977) which graphically describes what it is like to receive an injury from a laser. Decker was not wearing goggles, which were available, when he received a 6 mJ, 10 ns pulse from a neodymium:YAG laser operating at 1064 nm. Although his vision was not lost completely in the exposed eye, he continued to have numerous floating objects in his field of view.

McKinlay and Harlen (1984a) reviewed the damage mechanisms over the different wavelength regions (ultraviolet, visible and infrared radiations). In a companion paper (McKinlay and Harlen, 1984b) they compared the threshold injury data with maximum permissible exposure (MPE) levels in the laser standards. They concluded that the MPEs were adequate to ensure the protection of most people. However, they did raise the question of exposure to blue laser radiation producing minimal photochemical repairable lesions. They suggested caution if such exposure is prolonged.

Mellerio (1991) summarised the interaction mechanisms for optical radiation and the potential for damage. Photochemical, thermal and ionisation mechanisms are considered.

Pleven (1986) and Bandle and Holyoak (1987) have published reviews of known laser injuries. In the first report, fourteen accidents in research environments were reviewed which occurred between 1973 and 1986.

Most of these occurred in France. Pleven's main conclusion was that although the accidents could have been prevented, there was concern at the ignorance of clinicians in dealing with the injuries. Over fifty cases are reviewed in the second paper: none from the UK. Although most of the accidents relate to radiation damage to the eyes, references are also made to fatal electric shock and radiation induced fires in medical applications.

Rockwell (1997) has reviewed laser accidents over the thirty two years from 1964 to 1996. The Rockwell Laser Industries (RLI) database covers 330 events of which 241 were eye incidents (220 resulting in eye injuries) and 89 related to skin or non laser beam incidents, discussed below. Eleven of the eye incidents involved laser show operators and 16 spectators although the details of the incidents are not reported. These represent 3.3 and 4.9% of the incidents in the database, respectively.

All of this data is used as input to make recommendations on MPE values. The MPE values can then be used to determine accessible emission limits (AELs) which consider the level of laser radiation people can be exposed to having made a number of assumptions, such as control measures. This is the basis of the laser classification scheme widely used throughout the world.

2.4.1 British Standards

Laser safety standards have evolved since soon after the laser was first successfully demonstrated. These standards have been applicable to all laser applications, including laser displays. They are intended to lay down manufacturing standards for laser products and include tables of maximum permissible exposure (MPE) levels for the two critical organs, the eye and the skin.

The development of the MPE level with the development of British laser safety standards can be followed to determine if the level has changed significantly since the first standard was published in 1964 (Ministry of Aviation 1964). The corneal MPE values are summarised in table 2.1 for a visible laser beam for a single exposure to a pulse of 0.01 s, an accidental exposure to a continuous wave (cw) beam assuming the natural aversion response of 0.25 s, and exposure to a train of pulses.

Table 2.1 Comparison of MPE for Visible Laser Radiation

Standard	Single Pulse 0.01 s	Accidental Exposure (0.25 s) to cw Beam	Exposure to Pulse Train for 1000 s, 100 Hz and 1 ms pulses (MPE/pulse)
Ministry of Aviation 1964	2 mJ m^{-2}	5 mJ m^{-2}	0.2 mJ m^{-2}
Ministry of Technology 1969	1 mJ m^{-2}	0.3 J m^{-2}	0.003 mJ m^{-2}
BS 4803: 1972	1 mJ m^{-2}	0.3 J m^{-2}	0.003 mJ m^{-2}
BS 4803: 1983	0.57 J m^{-2}	6.36 J m^{-2}	1 mJ m^{-2}
BS 7192: 1989	0.57 J m^{-2}	6.36 J m^{-2}	1 mJ m^{-2}
BS EN 60825: 1992	0.57 J m^{-2}	6.36 J m^{-2}	1 mJ m^{-2}
BS EN 60825-1: 1994	0.57 J m^{-2}	6.36 J m^{-2}	1 mJ m^{-2}

It can be seen that the MPE level has remained unchanged since the publication of BS 4803: 1983. Guidance document PM19 contains a table which agrees with the 1983 and later values in table 2.1 for the single pulse and cw exposure situation. However, the scanned condition is not specifically addressed. The only change to

the MPE values since the laser was first used in laser light shows appears to be the relaxation in all three values in table 2.1 between 1972 and 1983.

The current British Standard (BSI 1994) contains three sections. Sections 1 and 2, definitions and manufacturer's requirements, respectively, are normative and should be complied with. Section 3 is the user's guide and there is a reference to the use of lasers for entertainment (sub-clause 12.4):

> Only Class 1 or Class 2 laser products may be used for demonstration, display or entertainment in unsupervised areas. The use of lasers of a higher class for such purposes should be permitted only when the laser operation is under the control of an experienced, well-trained operator and/or when spectators are prevented from exposure to levels exceeding the applicable MPE.

The British Standard recognises that laser radiation is not the only hazard which needs to be addressed. Clause 11 considers these 'hazards incidental to laser operation'. The rationale behind the inclusion of other hazards for lasers is based on incidents over the last thirty five years.

Many lasers operate at high voltages, or at least have an input from the mains supply (230 V in Europe). The laser assemblies are also heavy, presenting a risk of mechanical damage to installers and others in the vicinity. The types of lasers used in the entertainment industry do not generally use chemicals such as fluorescent dyes. However, in industry such materials are widely used and need to be subject to special care. The review of laser-related incidents by Rockwell (1997), reports non-radiation laser incidents as follows: 24 fires; 12 electric shock incidents (5 of which were fatal) and 4 embolisms (gas injection into blood stream), three of which were fatal. There were also 11 other incidents of a similar nature which were as a result of, for example, equipment failure. There is no specific data on incidents involving lasers in the entertainment industry.

This analysis demonstrates that non-laser radiation hazards have killed people. Certainly high voltages will be present around many entertainment lasers. High power lasers will also have the potential to cause fires and there is some anecdotal evidence that they have done so in entertainment venues.

2.4.2 International Standards

Most British Standards involving lasers are initiated and developed through the work of the International Electrotechnical Commission technical committee 76. The current British Standard on laser safety is technically equivalent to IEC 60825-1: 1993 (IEC 1993). It was recognised by the members of technical committee 76 that the base standard did not give adequate guidance for the use of display lasers. This was developed in a Technical Report, IEC 60825-3: 1995 Guidance for Laser Displays and Shows (IEC 1995). The status of this document is that it is a code of practice and not a standard.

IEC 60825-3 builds on the Australian code of practice reviewed in section 2.2.3. Ancillary personnel and performer MPEs are introduced to recognise that these persons may be trained in laser safety issues, something that cannot be assumed for the audience.

The International Radiation Protection Association (IRPA) Non-Ionizing Radiation Committee published guidelines on protection against non-ionising radiations in the journal Health Physics. These have been compiled into a comprehensive manual (IRPA, 1991). This includes a chapter on guidelines on limits of exposure to laser radiation of wavelengths between 180 nm and 1 mm. In May 1992 IRPA established an independent scientific organisation - the International Commission on Non-Ionizing Radiation Protection (ICNIRP). This body revised its laser radiation guidelines in 1996 (ICNIRP, 1996). The exposure limits are identical to the maximum permissible exposure limits in the IEC standards.

The American Conference of Governmental Industrial Hygienists (ACGIH) publish threshold limit values (TLVs) for physical agents, including lasers. The TLVs from the 1992-1993 edition are incorporated into a proposed European Directive on Physical Agents (CEU, 1994). Again, the expressions used for the TLVs are identical to the maximum permissible exposure values in the IEC standards for the visible part of the electromagnetic spectrum.

2.4.3 Summary of Standards

Laser safety standards have primarily been developed for the manufacture of equipment such that persons are protected from exposure to laser radiation. The inclusion of other hazards has been recent. The maximum permissible exposure levels have remained constant within the visible part of the electromagnetic spectrum since about 1983. The same standard is applied throughout the world, produced by the International Electrotechnical Commission. The scientific basis for the maximum permissible exposure levels continues to be studied by the International Commission on Non-Ionizing Radiation Protection. It is significant that the maximum levels of exposure for the visible region of the electromagnetic spectrum is identical in all of the standards, although the terminology may be different.

None of the standards use risk assessment, except within IEC 60825-1 for the use of class 1. Sub-clause 9.2 uses the concept of "reasonably foreseeable conditions of operation" in the definition of a class 1 laser product.

2.5 Legislation

The regulation of the use of lasers in the entertainment industry is complex. Many of the concerns from the laser display industry were from the confusion as a result of this complexity. Health and safety legislation applies to all work activities, irrespective of where that work is carried out. There is no specific health and safety legislation covering the use of lasers. However, much of the work will be subject to non-laser-specific health and safety legislation covering general health and safety, specific hazards and specific work activities. Some laser display events will require an entertainment licence. Some laser-related equipment will be subject to legislation concerning its supply.

2.5.1 Enforcement of Health and Safety Legislation

The principal health and safety legislation in the UK is the Health and Safety at Work etc Act 1974 (HMSO 1974). This legislation was the result of a report from a Committee chaired by Lord Robens (Robens 1972) into the status of health and safety legislation in the UK. Significantly, the Committee was asked to consider whether changes to legislation were needed to protect members of the public from hazards "arising in connection with activities in industrial and commercial premises". The report from the Committee describes a number of incidents where members of the public have been killed or injured as the result of the work activities of others. Most legislation at the time only dealt with the health and safety of employees and the recommendations from various official tribunals and investigations had not been addressed. Section 1 of the Health and Safety at Work etc Act states that one of the aims of the Act is to protect people who are not employees but who may be at risk due to the activities of people at work. This provision clearly applies to the public attending an entertainment event where lasers are used and the laser display company's staff, and others, are at work.

The enforcement of health and safety legislation in the UK is either by the Health and Safety Executive or by the local authority. The division of responsibility is laid down in the Health and Safety (Enforcing Authority) Regulations 1998 (HMSO 1998), which replace earlier Regulations (HMSO 1989).

A summary of the relevant premises where the Health and Safety Executive (HSE) and local authority (LA) will be the enforcing authority are presented in table 2.2.

Table 2.2 Enforcement of Health and Safety Legislation

Premises	Enforcing Authority
Laser Company's Premises	Generally HSE
University Campus	HSE
Arts, Sports, Games, Entertainment or Other Cultural or Recreational Activity	LA
As above, but LA is Owner or Operator	HSE
Fairground	HSE
Radio, Television or Film Undertaking	HSE
Sea-Going Ship	HSE
Zoo or Wildlife Park	LA

It can be seen that HSE are the enforcing authority for a greater range of types of establishments where lasers may be used for entertainment. However, the number of premises falling within the "Arts, Sports, Games, Entertainment or Other Cultural or Recreational Activity" category are large. Enforcement within the local authority is generally carried out by Environmental Health Officers (EHOs), whose duties may also extend to enforcement of the Public Health Acts.

The Health and Safety Executive is a national body. The enforcement is carried out through regional inspectors who can call on specialist inspectors when necessary. At the time of writing, the HSE had four specialist inspectors with responsibility for radiation, including lasers. These, in turn, are supported by a member of staff from the Directorate of Science and Technology who develops HSE guidance in this area and represents the organisation at national and international level.

Local authorities operate autonomously throughout the UK and, in England, may by a county council, if there are no district councils within the county, district councils, London borough councils, the Common Council of the City of London, the Sub-Treasurer of the Inner Temple, the Under-Treasurer of the Middle Temple or the Council of the Isles of Scilly. In Scotland the local authority is a council for a local government area and in Wales a county council or a county borough council. Therefore, there are many local authorities, all of which may have a number of staff who enforce health and safety legislation.

2.5.2 Health and Safety Legislation

The Health and Safety at Work etc Act is an enabling Act. There are a number of Regulations, made under the Act, which are, or could be, relevant to the use of lasers for entertainment. These are summarised in table 2.3.

Risk assessment is introduced in the Health and Safety at Work etc Act. The concept of "so far as is reasonably practicable" to ensure work activities are "safe and without risks to health" is used throughout. The duty applies firstly to the employer, but also to the designer, manufacturer, supplier and installer as well as generally to the employee. All of these are important for the laser entertainment industry, but perhaps the most important is the last. The employees setting up and operating a laser display will need to ensure that the laser display is safe and without risks to health. The Act gives no guidance on how safety should be demonstrated and risks assessed.

Table 2.3 Safety Legislation Relevant to the Use of Lasers in the Entertainment Industry

Title	Abbreviation
Health and Safety at Work etc Act 1974	HSAWA
The Reporting of Injuries, Diseases and Dangerous Occurrences Regulations 1995	RIDDOR
Ionising Radiations Regulations 1985	IRR
Electricity at Work Regulations 1989	EAWR
Management of Health and Safety at Work Regulations 1992	MHSWR
Provision and Use of Work Equipment Regulations 1992	PUWER
Manual Handling Operations Regulations 1992	MHOR
Workplace (Health, Safety and Welfare) Regulations 1992	WHSWR
Personal Protective Equipment at Work Regulations 1992	PPEAWR
Health and Safety (Display Screen Equipment) Regulations 1992	HSDSER
Control of Substances Hazardous to Health Regulations 1994	COSHH
The Health and Safety (Safety Signs and Signals) Regulations 1996	SSR

The Management of Health and Safety at Work Regulations 1992 (HMSO 1992) requires a "suitable and sufficient" assessment of the risks from a work activity to be carried out (Regulation 3). Again, little practical guidance is provided in the Regulations on how to achieve this. General practical guidance has followed the introduction of the legislation after recognition by the HSE and others that many small and medium size businesses did not understand what was required for a suitable and sufficient assessment of risks. Indeed, many businesses appeared to consider that such assessments did not apply to them, and were only an issue for the chemical or nuclear industries. The "Five Steps to Risk Assessment" was a simple approach to risk assessment which is applicable to many work activities (HSE 1998). HSE also recognised that the issue was risk management and not only risk assessment (HSE 1995).

There is no specific health and safety legislation relating to the use of lasers. The general legislation described above applies in many cases. Where national or international standards, or industry-specific guidance exists, these may be used as a measure of good practice for the practical application and enforcement of the general health and safety legislation.

2.5.3 Entertainment Licensing Legislation

Certain entertainment activities are licensed by local authorities. The officers may be from the Environmental Health department and therefore also involved with the enforcement of health and safety legislation or they may be in separate departments. Different legislation applies in different parts of the UK and in certain types of venue. The different legislation is summarised in table 2.4.

"Reasonableness" is used in licensing legislation as opposed to "as far as is reasonably practicable" in health and safety legislation. Reasonably practicable is taken to mean that the time, trouble, cost and physical difficulty of taking steps to avoid the risk are not wholly disproportionate to the risk. The size or financial position of the employer is not taken into account in this calculation. However, reasonableness may go further and local authorities may impose requirements under the entertainment licence which will achieve higher standards than those required under health and safety legislation (HMSO 1993).

Table 2.4 Entertainment Licensing Legislation

Legislation	Comments
Local Government (Miscellaneous Provisions) Act 1982	Applies to England and Wales (except London). For open air events, safety is a specific consideration. Uses the concept of reasonableness. Licence conditions can be specified. Covers public dancing or music or "any other public entertainment of a like kind".
London Government Act 1963	Applies to London. No distinction between indoor and open air events.
Civic Government (Scotland) Act 1982	Applies to Scotland. Covers locations where payment of money or money's worth is made for entertainment or recreation.
Private Places of Entertainment (Licensing) Act 1967	Applies to private premises operated for private gain and public not admitted.
Theatres Act 1968	Covers theatres where dancing or music do not form a significant part of the entertainment.

2.5.4 Product Supply Legislation

Article 18 of the Single European Act (EU 1987) introduced Article 100 A to the Treaty establishing the European Economic Community. Article 100 A established the internal market, ie provided for the free movement of goods between member states which should provide a basic level of health and safety to consumers. The Electrical Equipment (Safety) Regulations 1994 (HMSO 1994) covers equipment operating between 50 V and 1000 V AC, which includes most electrical equipment involved in laser displays. The Regulations refer to harmonised standards which should be used as the guide to the essential health and safety requirements such equipment should be expected to meet. In terms of laser equipment this will be the current British Standard on laser safety (BSI 1994).

Although the Electrical Equipment (Safety) Regulations were made under consumer law (Consumer Protection Act 1987) and are generally enforced by Trading Standards Authorities (Department of Trade and Industry), the Regulations are also relevant to workplace legislation such as the Health and Safety at Work etc Act 1974 and the Provision and Use or Work Equipment Regulations 1992, where the Health and Safety Executive or Local Authority Environmental Health Officers will be the enforcing authorities.

2.5.5 Summary of Legislation

It can be seen that the legislation concerning the use of lasers in entertainment is complex. The complexity is compounded by the lack of specific legislation for the use of lasers. The enforcement of the general legislation may be by different agencies and different groups of people within those agencies.

In summary, health and safety legislation will always apply. The enforcement will either be by the Health and Safety Executive or the local authority. Entertainment legislation may apply. If dancing or music forms part of the entertainment then it probably does apply. This is enforced by the local authority. Mains-powered equipment supplied as part of the laser display may be subject to product legislation. Enforcement of the supply will be by the Department of Trade and Industry, but there may also be implication under health and safety legislation.

The role of the police and fire services also need consideration. The use of lasers may cause a disturbance if used in the open air. The fire service may be involved due to the use of high voltages, water and the risk of fire from laser radiation.

Open air use of lasers may have an effect on air safety. The Air Navigation (No. 2) Order 1995 (HMSO 1995) can be used to control the use of lasers. Persons can be prosecuted for endangering the safety of aircraft (Article 55) or for exhibiting lights which may endanger aircraft taking off or landing, or which may be mistaken for landing lights (Article 99). The author assisted with drafting guidance for the use of lasers in airspace (CAA 1998). Airspace safety is enforced in the UK by the Civil Aviation Authority.

2.6 General Risk Assessment

It is obvious from the literature that no specific guidance is available for undertaking risk assessment for the use of lasers in the entertainment industry. There is limited guidance on risk assessment for the entertainment industry as a whole. However, other sectors such as the chemical and nuclear industries have been undertaking risk assessments for a number of years.

The Health & Safety Executive (HSE) published a report which looked into the tolerability of risk from nuclear power stations (HSE, 1988). This introduced the concept of 'individual risk' as compared with the 'societal risk'. The individual's perception of risk is very dependent on their perception of whether there is a positive benefit to them and whether their exposure to the risk is voluntary. The HSE use this concept further in a document on quantified risk assessment (HSE, 1989).

Death has been the usual outcome that has been associated with risk. However, the quality of life is now recognised as being important. One of the simplest ways of quantifying a risk is to take the number of incidents of a particular outcome per unit time or number of times the activity took place. However, consideration also has to be given to circumstances where the link between the cause and effect is not certain and some assumptions have to be made, and where no incidents have occurred, either because the probability of the outcome is very small or because the activity has not yet commenced. In this case 'best estimates' are used (Royal Society, 1992).

Taking the specific case of a family attending an entertainment event which includes the use of lasers, the perception will be that the risk to them is zero. The tolerability of risk will also be low. For a specific event it will not be acceptable to expose the public to a known hazard without quantifying the hazard and minimising the risk, taking account both the probability of exposure to the hazard and the consequences of exposure. In this sense best estimates could be used provided the hazards have been identified and quantified. It would be reasonable to expect control measures to be implemented if the risk was too high.

This approach is used, for example, when considering crowd management at entertainment events. Some of the incidents have resulted in many deaths, for example in Jerusalem in 1834 500 people died; 190 children died in a stampede against a restricted doorway in a theatre in Sunderland in 1883; and 99 football supporters died when they were crushed against a barrier in Hillsborough in 1989 (Kletz 1993). The significance of these incidents is twofold - first the number of people involved; and second the apparent inordinate amount of time before anything is done about the risk of repeat incidents. The Pop Guide (HMSO 1993) provides formulae for calculating the maximum number of people inside an event to minimise the risk of crowd-related problems. The HSE have also produced a guide on managing crowd safety (HSE 1996b) which is a practical guide to the safety issues which need to be considered. The parallels with laser safety in the entertainment industry are clear. A large number of people have been exposed to the hazard for a number of years and the potential for causing injury to a large number of people exists.

The military have been interested in the use of probabilistic risk assessment for laser safety for some years (Smerden 1986, Gardner and Smith 1995). The use of laser range finders on aircraft during training flights can potentially give rise to public exposure. The nominal ocular hazard area can extend over many square kilometres if taken literally from standards. The argument suggested is that although the MPE may be

exceeded, the actual probability of exposure is very small. To support this, the concept of the minimum ophthalmoscopically visible lesion (MOVL) is used, which is assumed to be a 30 µm retinal lesion. An acceptable risk level of 10^{-8} is used. Whilst this approach may be acceptable for military applications, it is less likely to be acceptable for routine public exposure in entertainment. An important factor is again the perception by the average family that the activity, ie going to a laser display, should be safe and without risk.

A formal approach to risk assessment is to consider the components of the laser display equipment and consider what can go wrong. There are a number of standard texts on methods for carrying out the analysis, for example (Cox and Tait 1991; Modarres 1993; Henley and Kumamoto 1992; and Kletz 1992). However, as pointed out by Kletz (1991) one of the major factors is the human being, either as the manager, or as the person carrying out a physical activity. A report from the Advisory Committee on the Safety of Nuclear Installations (ACSNI 1993) supports this view and suggests that a positive safety culture is very important. An analysis of the individual components of each laser display may not be viable considering the time constraints, certainly on temporary installations. However, for permanent installations, if the risk of exposure is high and the number of people at risk is large, then it may be appropriate to utilise the more formal techniques such as hazard and operability studies, hazard analysis and failure modes and effects analysis. However, as stated above, the nature of the industry is such that assumptions may still need to be made about the human factors in the assessment.

2.7 Training

Section 2.6 has identified the importance of the human element in the assessment of the risks. Training can form an important part of risk management. The current laser safety standard (IEC 1993) provides some guidance on the training required for users of class 3A or higher laser products. The standard suggests that this training should include:

- familiarisation with system operating procedures
- the proper use of hazard control procedures, warning signs, etc
- the need for personal protection
- accident reporting procedures
- bioeffects of the laser upon the eye and the skin

The standard also requires a Laser Safety Officer to be appointed if a laser of class 3B or class 4 is used.

Vassie et al (1993) reported that many of the laser manufacturers in the UK had difficulty understanding the current British Standard on laser safety. Many purchasers of laser products will rely on the manufacturer for education and training in the first instance. It would be reasonable to expect laser display companies of some standing to have laser safety training programmes which include all of the hazards from working in the industry. It would also be reasonable to see customer training provided, perhaps under the guidance of the company Laser Safety Officer.

Trade associations often have an important role in the maintenance of practical standards for particular industries. However, the development of such associations, particularly in the UK has to be seen in the context of the competition between laser display companies. Many companies have spawned other companies through personal differences between employers and employees.

The International Laser Display Association (ILDA) is a US-based organisation founded in August 1986. It publishes its own journal (Laserist) and holds an annual conference. There are currently seven committees: Awards; Technical; Safety; Ethics; Terminology Standardization; Planetaria and Science Centers; and Public Awareness. ILDA publish (ILDA 1993) a glossary of terms used in the laser entertainment industry aimed primarily at new laser operators and technical standards.

A Canadian laser display company, Laser F/X International publishes its own journal for the laser light show industry (Laser Effects). This has a worldwide circulation. Laser F/X International also organises an annual laser light show conference and exhibition which includes tutorial sessions.

Both ILDA and Laser F/X International operate sites on the Internet, with electronic mailing lists for the exchange of information.

There is no major involvement of UK laser display companies in these two ventures.

Following a joint presentation of new guidance by the Health and Safety Executive (HSE 1996a) by NRPB, Loughborough University and the Health and Safety Executive on 8 January 1997, many of the laser display companies got together and formed a professional association. Initially this was called the British Entertainment Laser Association, but the "British" was deleted within a couple of months to avoid limiting the membership to the UK. The birth of this organisation could be seen to be as the result of implied tighter regulation of the industry and therefore was initially a pressure group.

2.8 Conclusions

There are a number of guidance documents covering the use of lasers in the entertainment industry. None of these give practical guidance on assessing the risks. Most of the documents are official, ie have been written by regulators rather by the industry. The guidance that has been written by the industry contains errors and demonstrates a lack of understanding of many of the safety issues.

The guidance for the exposure of persons, and particularly members of the public, to laser radiation is consistent and clear. People should not be exposed to laser radiation in excess of the maximum permissible exposure (MPE). The values for the MPEs are internationally agreed and have remained the same for the visible region of the electromagnetic spectrum since at least 1983. However, there is no clear guidance on how to assess laser shows for compliance with the MPE values.

The enforcement of the use of lasers in the entertainment industry is complex and needs to take account of health and safety legislation, entertainment licensing and product legislation. The enforcement is likely to be spread over different agencies, and many enforcing officers are unlikely to deal with the entertainment use of lasers regularly, even in major population centres.

Laser radiation is unlikely to kill people. Many of the associated hazards, such as electricity, working at height and manual handling do have a risk of death. There is specific legislation covering many of these hazards and general entertainment industry guidance. However, laser displays are usually seen in isolation, as is clear from the guidance documents available.

Industries who work together in professional associations tend to develop their own standards, both technical and safety. The laser display industry in the UK is highly competitive with a high degree of animosity between companies, many of which share evolutionary paths. This is likely to lead to a reluctance to be open about the technology used for laser display products.

The conclusion is that the industry is likely to be very protective of its activities, especially as there appears to have been little formal involvement of regulatory authorities in assessing the risks from actual performances. The prevailing view of the laser companies is that they have been carrying out this activity for a number of years and that they know what they are doing. The view of the regulators is likely to be that the industry is not helpful and probably not able to demonstrate the risk management of their activities. Such views are likely to see each party on either side of a ravine with a large gap of understanding between them, but each, hopefully, will have the common aim of seeing the safe use of lasers in the entertainment industry. It was clear,

therefore, that it was necessary to understand the technology and issues associated with putting on a laser display, the practical approach to assessing the risks, and the problems of enforcement. In essence, the laser display companies had to be able to provide risk assessments which were meaningful, and which could be assessed by enforcing officers to ensure legal compliance. If this could be achieved, it should be possible to build a bridge between the two opposing sides and ensure the safety of all who attend entertainment events using lasers.