6. Laser Hazard Assessment Model

6.1 Introduction

The previous Chapters have outlined the problem for both enforcing officers and those involved in the laser entertainment industry. Although there are many aspects to consider it is important to appreciate that most are common to both groups of people. The aim was to develop a methodology to enable a suitable and sufficient assessment of the risks associated with the laser display to be carried out. Before the risks can be assessed it is necessary to identify the hazards. One of the main issues has been consistency of approach to assessing the laser safety issues. The laser companies do not consider safety a big issue. They are generally working on tight financial margins and most have not experienced major injuries.

The survey of the enforcing officers and feedback from the training provided suggested that few, if any, of them were in a position to assess the safety of laser displays. Where training has been provided the skills are not developed due to the small number of assessments which may be undertaken by a particular officer. A methodology is needed to ensure that the enforcing officers can work through the key elements of the safety issues. It may still be that they will not be able to carry out complete assessments but at least they should be in a position to appreciate where further assistance is required and where they can call on their existing expertise to assess much of the installation.

It is also ideal to develop a methodology which is helpful to the laser companies. Whilst it is easy to conclude that they do not care about the safety issues, it may be that they have not been forced to think them through. A successful methodology may also provide commercial benefits to laser companies. Demonstrating professional competence, which includes assessing the safety issues, is becoming increasingly important in the entertainment industry. This information will be useful for venue managers and promoters as well as to the enforcing officer.

This Chapter describes the development of a model which can be used by all parties, and which covers all applications of lasers in the entertainment industry. The methodology should provide a structured approach to identifying hazards which can then be input to a risk assessment. It will be seen that the development of the formal guidelines, both national and international should have provided ideal opportunities for the introduction of a suitable risk assessment methodology. However, this was not to be the case. The involvement and influence of both the International Laser Display Association and the Entertainment Laser Association are described.

6.2 Development of Initial Assessment Checklist

One of the main comments from local authority Environmental Health Officers concerning laser displays is that they would prefer to work to a prescriptive hazard identification checklist. To a certain extent HSE PM19 (HSE 1980) provided this. However, the document did not go far enough. The aim through the current research has been to produce a methodology which was useful to the enforcing officer but also had benefits for the venue management and the laser company. The latter should see an improvement in efficiency and management of laser displays. The approach would also go some way to remove inconsistencies between enforcing officers which has been a justifiable criticism made by many laser companies.

A generic model for laser hazard assessment has been developed by Tyrer et al (1994). This model treats the laser, beam delivery and workpiece as separate parts of any laser product. However, for the entertainment and display industry this model can be developed further into a checklist. One of the benefits of this approach is to ensure that any hazard assessment is carried out in an efficient and systematic manner, thus minimising the possibility of any areas being overlooked.

Apart from considering the laser display as a series of modules it is also necessary to consider the modules and hazards as a function of the life cycle of the display. The stages of the life cycle can be summarised as follows:

Planning - liaison with “customer” and deciding format
Manufacture - physical manufacture and assembly of components
Testing - make sure everything works
Transport - move the equipment to the intended site
Installation - assembly on site
Alignment - generally optical alignment
Performance - the laser show
Maintenance - carried out by the user on a regular basis
Servicing - usually carried out by manufacturer
Modification (if permanent) - upgrades, etc
Dismantling - take the system apart
Disposal (eventually) - when the system is no longer required.

During the life of the equipment or the show, the different stages of the life cycle will be revisited as shown in figure 6.1. Different people may be at risk from the identified hazards at different stages of the life cycle. Different parts of the life cycle may also take place in different locations with different degrees of control possible. The Pop Guide (HMSO 1993) stresses the importance of the planning stage. Generally, many of the problems experienced at the other stages of the life cycle should have been addressed, or at least foreseen, at the planning stage. It is certainly important that the laser company ensures that any enforcing authorities are involved at this stage in order to identify any specific requirements including written assessments.

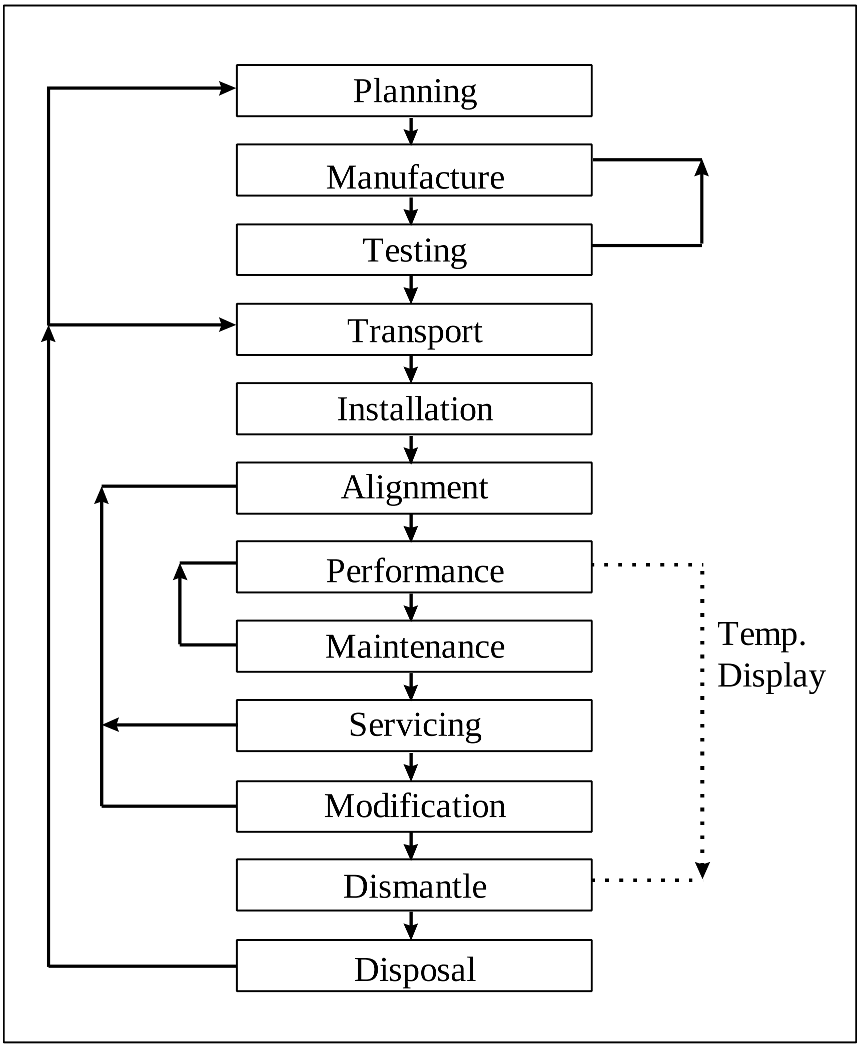

Figure 6.1 Life Cycle of a Typical Laser Display

6.2.1 The Checklist

All parties involved with laser displays had identified a need for a methodology to permit assessments of laser displays to be made. This could be a simple check list but more importantly it is considered that the approach to the assessment must be methodical and systematic, ensuring that all aspects are covered.

A typical laser display can be divided into ten modules, each of which may have hazards associated with it. The mnemonic from the ten sections is SCALE DOVES after the first large outdoor laser display audited by the author, where the laser company projected laser images onto trees in the form of doves to Edvard Grieg's Morning from Peer Gynt. SCALE DOVES is expanded as follows:

S	Staff involved with the event other than those involved directly with the laser
C	Control system for the laser
A	Audience
L	Laser
E	Equipment associated with the laser
D	Delivery optics
O	Operator
V	Venue
E	External factors
S	Support system

The potential hazards associated with each aspect of the items on the checklist are described in the following sections.

6.2.1.1 Staff

There will always be a number of staff at a venue who will not be directly involved with the operation of the laser. These will include lighting and sound engineers who, if the performance is temporary, may be unfamiliar with the venue, although they may have worked with the laser company at other venues. The venue staff may include management, engineers, audience control staff and vendors. All of these are likely to consider that any safety instructions or notices do not apply to them. Indeed, many will have "All Areas" passes which they will consider will give them access to all areas irrespective of the risks of doing so.

The factors to be considered include the potential for access to the laser, its control system and the laser radiation. The latter will be particularly important during the setting-up and alignment stages.

A further group of staff who should be considered are other third parties, such as first-aiders and merchandise/food vendors. These may not be employed by the venue but are more likely to take notice of safety advice. However, they could be at risk during the setting-up and alignment stage.

The hazards arising from, and to, the staff are summarised as follows:

- Unauthorised access to the laser (eg high temperatures, cables, pipes, high voltages, laser radiation)
- Unauthorised access to the beam delivery system (primary and secondary) and therefore to the laser radiation and, possibly, moving parts
- Unauthorised access to the laser control system (exposure of other persons to laser radiation)
- Accidental or deliberate exposure to the laser radiation (possibly through another's actions)
- Unauthorised or accidental exposure to high voltages
- Unauthorised or accidental exposure to cooling system
- Trip hazard arising from various cables and pipes
- Mechanical hazard during laser installation

6.2.1.2 Control System

The laser show control system may be sited close to the laser, or one of the lasers if more than one is in use. A central control system may be used or there may be distributed control with some form of communication between the operating staff. Most modern control systems are either personal computer (PC) or microprocessor based. These can introduce considerable flexibility for the laser operator. The signals from the control system to the laser and its optical system need to be considered. If the laser is remote from the control system then the signal cable may pass through the audience. This exposes the cable to potential damage and the resulting action of the laser and its optical system needs to be considered. There may be a radio link. If this is interrupted or interfered with, will the optical system fail to safety?

If the control system is software based then it is very difficult to ensure that all conditions have been tested. A certain set of conditions may not occur for many years but, when they do occur, they may result in a hazardous condition being created. The action of the laser and the optical system should be considered if the computer program 'crashes'.

The integrity of the computer/control system hardware should also be considered. Temporary installations should make use of ruggedised equipment, which will survive the rigours of transport. Again, the action of the laser and optical system need to be considered if the hardware fails.

The hazards associated with the control system can be summarised as:

- Failure of the control software
- Failure of the control hardware
- Links between the control system and the laser(s)
- Links between the operators if more than one control system is used

Any one of these eventualities could result in unintentional exposure of persons to laser radiation.

6.2.1.3 Audience

If the laser company complies fully with the published guidance (HSE 1980 or HSE 1996a), the potential for hazardous laser radiation exposure of the audience should be restricted to failure conditions. However, as demonstrated in chapter 3, this cannot be assumed. The analyses in chapter 5 demonstrate how complex quantification of the hazard can be.

The audience may be exposed to laser radiation, either directly (static or scanned beams) or from reflections (intentional or accidental). The pathways for exposure need to be considered carefully and methodically. If blanking plates are used to restrict the directions of the laser radiation, the potential for audience access to the radiation outside of the blanked-off area needs to be considered.

The lasers or their control systems may be within the audience, especially during temporary events. Measures should be introduced to ensure that the audience cannot access any of these. The potential for unruly behaviour should be taken into account: this is less likely during a product launch than during a rock concert, for example.

The audience may have access to items which could be put into the path of the laser radiation, such as reflective, helium-filled, balloons. Control measures to ensure that such items are not for sale at the venue or brought into the venue need to be considered.

The factors relating to the audience are summarised:

- Access to the laser radiation
- Access to the laser
- Access to the optical systems (primary and secondary)
- Access to the control system
- Audience behaviour
- Audience position and control

Potential for introducing reflective items into laser beams
Access to systems associated with the laser, such as high voltages and cooling systems

6.2.1.4 Laser

The potential for hazards from the laser display will relate fundamentally back to the laser. If a class 1 laser product is used, the hazard from laser radiation is considered low. However, if the laser is class 4 then the potential for serious injury exists.

The radiation levels can be compared with the maximum permissible exposure levels. The characteristics required are: wavelength, radiated power, duration of exposure, beam diameter and beam divergence. For entertainment and display purposes the laser will generally be emitting visible radiation. However, the potential use of lasers emitting non-visible radiation, for example in the ultraviolet region, to produce special effects, should not be ignored. Some lasers will also potentially generate radiation in addition to visible wavelengths, such as a frequency doubled neodymium:YAG laser or flashlamp pumped lasers. Good engineering design should ensure that the risk of access to such unintentional radiations is minimised.

The hazards associated with the laser itself can be summarised as:
Laser radiation
Non-laser radiation (including x-rays and ultraviolet collateral radiation)
Mass of the laser
Temperature of the laser housing

6.2.1.5 Equipment Associated with the Laser

The laser requires services to operate. These may include high voltage power supplies and cooling systems. There are also a number of other associated pieces of equipment which assist the display itself. These should all be identified and any hazards recognised. Examples of such equipment are smoke generators used to make the laser radiation visible to the audience and the radio communications equipment used for ensuring that a multi-operator laser show is co-ordinated.

The hazards resulting from the associated equipment can be divided into the following categories:
Hazard to the operator (trip hazards, high voltages, water, etc)
Hazard to other staff (trip hazards, high voltages, water, etc)
Hazard to the audience (hopefully few, but may include smoke/vapour from smoke generators)
Hazard to the laser (eg, water leakage)
Hazard to the optical system (eg, water leakage)

6.2.1.6 Delivery Optics

Although it is possible to have a laser display with a single beam emitted from the laser, it is more likely that there will be an optical system attached to the front of the laser which modifies the direction and/or characteristics of the radiation. In addition, there may be other optical components remote from the laser position such as mirrors or mirror balls.

The primary delivery optics, attached to the laser, are usually controlled remotely. The beam direction may be restricted by the use of blanking plates or by software within the control system. There is the potential for the blanking plates to move and for the software to be programmed incorrectly. There is also the potential for the laser operator to consider that irradiating the audience is not a problem (see appendix B).

The beam direction will probably be controlled by at least two orthogonal mirrors attached to galvanometers. The natural rest position of the galvanometers will have to be considered and the resultant beam position if any number of the drive circuits fail. Beam expanding optics may be used for a beam which is to irradiate a mirror ball. The hazard associated with the beam expander failing to engage needs to be considered. A number of the components in the optical system may present a mechanical hazard to the operator during alignment.

The secondary optics may include items forming part of the structure of the venue or the stage set and may be difficult to predict until the display is performed.

The hazards associated with the beam delivery system are summarised as follows:

Laser radiation exposure of the operator
Laser radiation exposure of the staff
Laser radiation exposure of the audience
Mechanical hazard for the operator during alignment

Fibre optic delivery systems may also be used. There is then the potential for high power laser radiation to travel up to tens of metres from the laser to the aperture. The path of such fibres should be considered, along with the potential for damage, disconnection, etc.

6.2.1.7 Operator

The laser operators are the critical components in a laser show at a temporary event. The safety of the entire laser display system will usually be under their control. The operators should have received adequate training to ensure that they are aware of the capabilities and limitations of the laser display and are aware of the potential safety issues. In a fixed installation, the laser system may have been engineered such that radiation exposure above the maximum permissible exposure levels is not possible and therefore it is possible to have an operator trained to a lesser degree.

The operator may be the person responsible for setting up the laser display, perhaps with a number of other people from the same company. There may be more than one operator for a large installation.

The operator is capable of introducing a number of hazards. The timetable for setting up the display should take into account the requirement to align the optical system before the audience arrives. However, other staff, including the operator, are potentially at risk during this stage.

Hazards connected with the operator are concerned with:

Lack of training
Laser radiation exposure of the operator
Laser radiation exposure of staff
Laser radiation exposure of audience
Lack of safety procedures and systems

6.2.1.8 Venue

Different problems are associated with fixed installations and temporary installations. In the former the initial hazard assessment should identify problems which can be rectified. For temporary installations, problems associated with the venue may not become apparent until the laser display company arrive on site. However, good advanced planning should minimise this.

Hazards likely to be associated with the venue are:

Specular reflecting surfaces
Audience in unexpected places (eg balcony)
Services not available or inadequate

6.2.1.9 External Factors

External factors will include the weather for an outdoor event. Rain will attenuate the primary laser radiation beam but may also introduce many reflecting surfaces. There is also the hazard arising from the high voltages associated with the laser. The weather may have an effect on the attitude of the audience and the concentration of the operator.

Consideration should also be given to other objects or fixtures which may be remote from the venue if they can alter any safety assessment. These will include buildings and aircraft.

6.2.1.10 Support System

The laser and optical system will usually be mounted on some sort of support system. Any secondary optical systems will also be mounted. In a fixed installation, the mountings will be semi-permanent and less prone to unplanned movement. In temporary installations the laser company will generally erect a temporary structure to mount the laser and primary optical system but they may rely on either existing structures or structures erected by other parties involved in the display.

Potential hazards connected with the support system are summarised as:

Instability of the support system
Specular reflections from the support system
Shared access to support systems
Audience access to support systems

6.3 Experience of Using the Checklist in Practice

The Scale Doves model was trialed at thirteen laser displays, both new permanent installations and temporary displays. Although it was possible to identify hazards, the following problems were identified:

The approach to the assessment was not in a logical order
There was confusion over what was a hazard, and what was at risk, particularly with the audience.
The checklist was accepted by enforcing officers as being better than nothing but was not considered useful by laser display operators.

The laser display companies treated the whole process with suspicion. It was still very difficult to obtain a real impression of the problems faced by the industry on installing fixed or temporary displays and producing performances to, often very tight, timescales. At this stage, contact was made with members of the International Laser Display Association in the United States who, it was considered, would have less direct concern with someone outside of the industry. This was really the starting point for building bridges between the industry and those who have to assess and perhaps regulate their practices.

The UK laser display companies were still producing notifications to enforcing officers using appendix 3 of PM19. However, it was becoming more obvious that such notifications had a small number of pedigrees (probably three). The information provided did not relate to specific venues and often not even to the type of event. Calculations provided were certainly not relevant. In most cases, the calculations had been followed through to give an answer for a single scan effect, which was just below the MPE, but with unjustified assumptions. Typically, it would be assumed that the beam divergence always increased after reflection from a plane mirror, and that the scan rate was hundreds of hertz.

6.4 Developing an Assessment Methodology

It was recognised that any methodology had to be useful to the laser display companies to ensure that they could demonstrate that a risk assessment could be undertaken and, if necessary, presented to enforcing officers. Equally, enforcing officers familiar with the same model would be in a better position to assess such risk assessments.

An important factor which arose during the development of the new methodology was the increasing requirement to provide documented safety assessments in other sectors of the entertainment industry, particularly relating to temporary structures. A small number of laser display companies recognised the benefit in being able to provide similar levels of documentation for their section of the industry. Multi-site entertainment companies were also requiring paperwork to demonstrate the professionalism of their contractors.

The original checklist was modified to include a number of additional parameters and presented in an order which, for most installations, is logical. For each compartment of the model, only the hazards associated with each compartment are considered. However, for each compartment it is still necessary to consider the life cycle of the display, as presented in figure 6.1, and who may be at risk from the hazards at each point in the life cycle.

The methodology is presented in figure 6.2. It can be seen that there is a logical progression from the laser along the optical path and then expanding out from the laser.

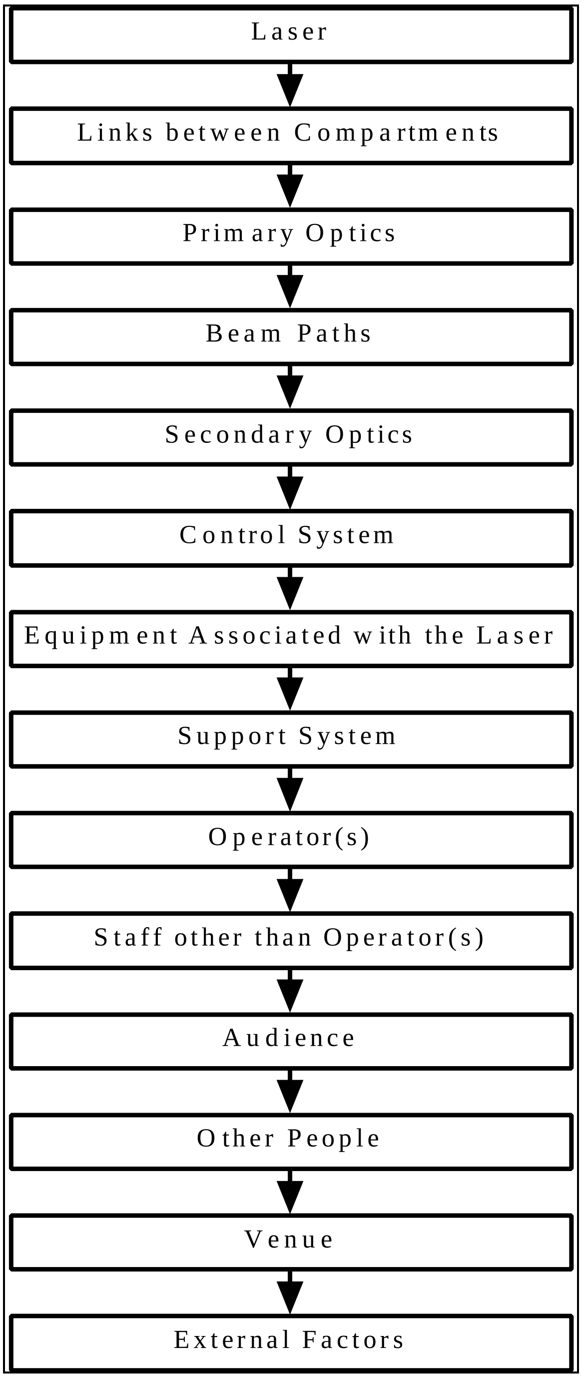

Figure 6.2 Laser Display Hazard Identification Methodology

Many of the compartments are identical to the earlier checklist. The differences are as follows.

6.4.1 Laser

It was recognised that there may be more than one laser and that each would have to be considered, although many hazards will be common.

6.4.2 Links between Compartments

This section of the model was primarily introduced to recognise that the connections between the different sections of the laser display can have hazards associated with them. However, it can also be used as a trigger to consider, for example, how the operator interacts with the control system.

The link between the laser head and the primary optics may be by direct mechanical coupling, via an air gap or through fibre optic cable. It is important to also consider the link between any services and the laser head, and also links between the control system, the optics and the laser.

6.4.3 Primary Optics

It was recognised that the primary and secondary optics had different hazards associated with them at different parts of the life cycle and, in general, would put different people at risk. Therefore, it was important that the difference was stressed by creating different compartments for these different optical systems.

The primary optics will generally be constructed on the premises of the laser display company, requiring only final alignment on site. It is also prudent to encase the primary optics, for safety and to minimise the influence of environmental conditions on the optical components. During normal operation, there should only be a single or small number of actual or potential apertures from the primary optics.

The mounting of the optical components within the primary optical system should also be considered.

6.4.4 Beam Paths

This compartment was introduced into the methodology to ensure that the beam paths are specifically considered. Apart from the justification from the assessments carried out in chapter 5, this also appeared to be an area where the laser companies exhibited a complete lack of understanding of the safety issues.

The assessment should include the paths between the primary optical system and any secondary optics. The previous chapter considered how the hazard from the beam paths should be quantified if personnel exposure is intended or reasonably foreseeable. However, even if beam paths are kept well away from areas occupied by the audience, the exposure of others should also be considered.

6.4.5 Secondary Optics

This compartment considers the mounting of the secondary optics, including any actual or required blanking. Since, by design, the beam path must be to the secondary optical components, the accessibility of both the beam and the optical component should be considered, both during alignment and cleaning, and by, for example, members of the audience.

6.4.6 Control System(s)

This is identical to the earlier checklist as described in 6.2.1.2.

6.4.7 Equipment Associated with the Laser

This is identical to the earlier checklist as described in 6.2.1.5.

6.5 Experience of Using the Methodology in Practice

The hazard identification methodology was tested at nine venues, both permanent and temporary. It was also tested by other NRPB staff to ensure that the breakdown of the problem into the different compartments was logical. The methodology was found to work successfully in identifying the hazards. However, it should be recognised that the model may need to be modified for specific events. Although all lasers displays assessed to date are covered by the model, as technology advances it is likely that the model may need to be extended. This should just be the addition of further compartments.

It was useful to apply the model to a laser display company during the development of new products and the demonstration of existing products. The persons at risk were well defined, and the life cycle and hazard identification methodology are still applicable. This proved to be a useful exercise for the laser company concerned in support of their risk assessment and health and safety policy statement.

The methodology was at an advanced stage of development when HS(G)95 was launched to the industry at NRPB on 8 January 1997. This was seen to be an opportunity to help the industry with a technique to assist with the practical implementation of the new guidance. It was also the first opportunity to raise the questions over the acceptability of audience scanning to a large number of companies at one time. The launch was also attended by managers from venues which use lasers and representatives from equipment manufacturers. Twelve of the largest laser display companies had the opportunity to comment on the new guidance document and the views on audience scanning. The companies felt that HS(G)95 did not meet either their requirements nor those of the enforcing officers. Each, as stated before, preferred a more prescriptive approach, with clear guidance on what can and cannot be done, and therefore little flexibility for interpretation which was considered to be inconsistent throughout the UK.

The result at the end of the seminar was the determination of the industry to form a professional association to look after their interests. Thus the Entertainment Laser Association (ELA) was formed, probably more as a pressure group than anything else. That this body should have been formed at all is significant. Most of the member companies had been spawned from a small number of pioneering laser display companies as the result of disagreements between individuals. They were also operating in a fiercely competitive market against a general view that lasers had had their day and often were staged in a less than professional manner.

It is interesting that some of those present at the meeting supported the views presented and particularly concerns over insurance issues for intentionally exposing the audience to laser radiation levels in excess of internationally agreed MPE levels. These included the venue managers and one of the laser display companies who already operated to a quality system for their non-laser work, such as lighting and sound installation.

ELA formed a number of sub-committees, including one covering safety. Presentations of the hazard identification methodology were made both to the sub-committee and to the ELA Committee.

6.6 Conclusion

A methodology has been developed for the identification of the hazards associated with the use of lasers for entertainment. This has evolved from a simple checklist to a logical methodology which considers the various modules of a laser display (figure 6.2) as a function of the life cycle and the persons at risk.

The involvement of the laser display companies with this research has been initially to be suspicious of the rationale behind any attempt to formalise the safety aspects of their industry. It was necessary to seek information and comments from non-UK laser companies, such as members of the International Laser Display Association, who felt less threatened by any involvement in their industry.

The introduction of revised guidelines in the UK (HS(G)95) and internationally (IEC 60825-3) should have provided the opportunity for clear statements of the safety requirements for laser displays and how these should be demonstrated. However, both documents failed to achieve this through a more general goal-setting approach. Neither document was developed with any significant input from the industry. However, the launch of the UK guidelines in January 1997 did trigger the formation of a UK-based professional body for the industry.

The hazard identification methodology was presented to the industry both formally and on an individual basis as work continued alongside a number of laser display companies and enforcing officers as displays took place throughout the UK.

Identifying the hazards is not the end of the story. It is necessary to follow this through to an assessment of the risks and finally to management of any residual risks. This, again needed to be supported by both the industry and the enforcing officers. The process will be explored in the following chapter.