9. Conclusions and Recommendations for Further Work

9.1 Introduction

The analysis of available guidance and text books relating to laser safety suggested that laser radiation issues were well understood (chapter 2). Therefore, the main issues initially covered by this research work were the non-radiation safety concerns. However, an analysis of several laser display events (chapter 3) suggested that laser radiation was still an issue. There was also a gulf between laser display companies and enforcing officers. This was believed to be due to a lack of understanding of each other's standpoint. The author's experience of dealing with enforcement officers, and the acceptance of NRPB by these organisations meant that liaison would be straightforward. Such collaboration with the laser display companies would have to be earned through mutual respect and understanding.

A survey of the understanding of laser safety within local authorities was well supported (chapter 4) and reinforced the impression that local authorities did not necessarily have specific expertise for assessing the safety of laser displays. Similar surveys of the laser community produced a disappointing response, suggesting suspicion of 'officialdom'. However some data was acquired from the laser display companies during a seminar held at NRPB.

It was necessary to gain a thorough understanding of the technology, techniques and day-to-day problems of putting on a laser display event. This required co-operation from a number of laser display companies who were prepared to spare time to be questioned and observed.

It was recognised that training and information were important to ensure that all parties understood each other's points of view and specific problems. To meet this need a number of joint NRPB/Loughborough University training courses were run specifically aimed at laser safety in the entertainment industry. These courses also helped to provide feedback on the main issues. However, they also demonstrated that the techniques developed at that stage were not giving the enforcement officers the confidence they needed to assess laser displays without further assistance. This was despite many of the safety issues being within their expertise. Therefore, it was necessary to modify the techniques developed into a risk assessment methodology which focused on the key risk issues and the people at greatest risk.

Audience scanning remained a key issue and one which, by measurement and theoretical assessment, appears to put the public at considerable risk of eye injury. However, this risk is not supported by reported incidents suggesting that the practice may not present as great a risk as predicted or that the number of eye lesions is significantly under-reported. The latter is thought to be the case.

9.2 Conclusions

A number of key issues have been resolved as a result of this research and it is strongly believed that the risk from the use of lasers in the entertainment industry can be managed successfully at least in part, by implementing the risk assessment methodology developed. The approach has been to solve a practical risk assessment issue, rather than a strict theoretical determination of the risks from the use of lasers in this industry.

The situation at the start of the research was as follows:

- laser display companies were not routinely assessing the risks from their work activities;
- laser display companies complained about inconsistent enforcement between enforcement officers;
- the enforcing officers found the laser display companies less than helpful and unable to convince them of any risk management considerations;
- the enforcing officers believed they had little understanding of the technology, methods of generating

laser effects, or the safety issues;

- the current practice by the laser display companies was less than professional, even when viewed from within the entertainment industry;
- audience scanning with laser beams was routinely taking place with no quantification of the hazard;
- there was a lot of folk lore about the safety of laser beams, such as beams being safe after reflection from a mirror, irrespective of incident power, and audience scanning is safe provided the beams are scanned fast;
- the laser display companies did not have a complete understanding of the technology they were using, including the scan speeds used;
- consultants were providing advice with little understanding of the key laser safety issues, adding to the impression that there were few safety issues.

Laser displays were routinely being assessed based on limited information provided on a proforma included as appendix 3 to the then UK laser display guidance, PM19 (HSE 1980). These proformas rarely related to the venue or the laser display equipment used and most enforcing officer either accepted them at face value or admitted they did not understand them. A major factor in the problem developing as far as it did was that the laser display companies and the enforcing officers did not communicate with each other and, probably did not trust each other.

The development of assessment tools has relied on breaking down the barriers between the laser display companies and the enforcing officers and attempting to build a bridge between the two. Therefore, the tools have needed to be useful to both parties and, as a result of this should also be useful to others, such as the venue management and event promoters.

In parallel with the development of the assessment tools has been the need to understand the technology used, the artistic techniques for producing laser shows, the problems of physically staging a laser show and the enforcement issues. In essence, it was necessary to work alongside laser display companies and see the world from their viewpoint, and also to work with the enforcing officers.

The development of the assessment tools has been an iterative process which has involved a number of hypotheses, testing those hypotheses and feeding the results back to new, further developed hypotheses. Existing guidance from the literature and laser safety standards suggested that laser radiation issues were well understood, but little practical guidance was available for identifying the non-laser-radiation issues. Therefore, the first tool developed was a checklist, termed SCALE DOVES. This was an attempt to structure the areas where the hazards may exist. The major success of this initial checklist was the identification of the problem of assessing laser radiation since intended audience scanning with laser beams was widespread. There was also some confusion with the checklist about what was a hazard and who was at risk from the hazard.

A hazard identification methodology was developed which used a logical path from the laser to the audience, the venue and outside. Hazards could be identified for each of a series of compartments of the laser display. The life cycle of the display was also identified as important. Planning, the first stage, was critical, but there were a number of stages and the hazards for each of the compartments could be different at each stage of the life cycle. It was also recognised that different people could be at risk from the different hazards in the different compartments at different stages of the life cycle.

The information that could now be collected for a laser display event was significant, or at least guidance was structured on the questions to ask. Presenting the information to the enforcing officer was now an issue. A Laser Display Safety Record was developed as a structured means of presenting the information and this approach was tested by a number of laser display companies for a number of events. Two key issues arose: the volume of paperwork required (with the amount of time and effort required to produce it); and the time necessary to assess it. On the positive side, the promoters and venue managers were very keen on the approach since it was a means of demonstrating a professional approach to the laser performance. Safety, they assumed would follow from that.

When considering the three variables for the risk assessment methodology: the compartments of the laser display; the life cycle; and the people at risk, it was apparent that the key risk issues occurred at specific regions of combination of the three variables. Although the laser display company staff and others in the immediate vicinity of their work may be at risk of death from their work, the audience generally were not. However, the number of people in the audience is generally much greater than the number of employees at an entertainment event. To maximise the effectiveness of a risk assessment, ie to implement effective risk management, it was important to consider the greatest number of people at risk, especially as a reasonably foreseeable outcome could be a serious eye injury. Such an outcome has the potential to significantly effect the quality of life of the persons at risk. Quantification of the laser radiation hazard during intended audience scanning suggested that the maximum permissible exposure (MPE) levels were being exceeded for situations where the power through a 7 mm diameter was more than about a factor of ten greater than the MPE for a static beam, ie 10 mW.

The risk assessment methodology was focused to take account of the key risk issues since time was generally a major issue, certainly for any enforcing officer required to review the risk assessment provided by a laser display company. Specific sections of the three-dimensional risk assessment methodology were taken which primarily considered the public: the alignment and performance stages of the life cycle; the laser beam paths, operator competence, control system and support system compartments; and the audience and other members of the public persons-at-risk zones.

The methodology could now be condensed into a flow chart for the enforcing officer to decide whether they have the necessary expertise to assess the safety of the laser display. The key issue will be whether audience scanning is an intended or reasonably foreseeable part of the laser show. If it is not, the assessment simplifies to a number of issues which the enforcing officer is likely to have experience of, such as the risk from mechanical and electrical hazards. If laser beams are an issue, or satisfactory conclusions cannot be drawn from the management of the risks from the identified hazards then the enforcing officer has a number of options: seek further advice on assessment of the risks; request further information to be able to make a judgment; or prohibit all or part of the performance.

Although the condensed methodology permits a reasonable assessment of the key risk issues, it will still be necessary to consider the remaining elements of the hazard identification methodology, even if these are not considered in detail.

One of the main control measures for many of the risks associated with the use of lasers in the entertainment industry is the competence of the operator(s). There is no nationally recognised training programme for laser display operators, although there is an initiative to develop such training generally for the entertainment industry by Loughborough College in the UK. This is intended to include laser display operators.

There is one remaining problem with the application of the methodology. It should certainly assist enforcing officers. A small number of laser display companies have also seen the benefits, including a number from outside the UK. However, the whole methodology is based on a requirement to convince someone else that the risks from the laser display have been adequately managed - the driving force for preparing the assessment is that the show may not take place if the assessment is not undertaken. However, many laser displays taking place in the UK will not be subject to entertainment licensing. As such, unless there is a culture change within the industry, or promoters and venue manager insist on reviewing risk assessments, these are unlikely to be completed for these other events. Adoption of the methodology resulting from this research should go a significant way towards ensuring that a consistent approach to determining the risks and how the assessment should be audited exists throughout the UK, if not the world.

There was a great deal of confusion amongst the laser display companies on the legislation that applied to the use of lasers in the entertainment industry and the status of published guidelines. These issues have been addressed in chapter 2. It will always be better for the laser company to approach the local authority to determine if they wished to be involved with an assessment of the laser safety issues than to find out that the enforcing officer stops the laser show on the night because they were not informed and should have been.

It had been hoped that the formation of the Entertainment Laser Association would provide an impetus for the industry to dispel its image of being less than professional and work towards self-regulation. This has not proved to be the case. The industry in the UK hangs on to the belief that their industry is safe and that audience scanning is necessary and without risk. This is based purely on the lack of reported injuries and not on any practical assessments. This attitude is in marked contrast to the international situation. The International Laser Display Association (ILDA) has taken this research very seriously and joint measurements have been carried out to confirm some of the basic premisses, such as the maximum irradiance that can be put into an audience, and that higher scan speeds do not make beams safer. It is also the intention of the ILDA Board of Directors to produce an international safety guide produced by the industry, which takes account of the methodologies and conclusions of this research.

Many of the UK laser display companies seem to consider that audience scanning is the most important part of the show. However, this view is generally not shared by the audience. Certainly, close proximity to laser beams is exciting and impressive but repeated scanning across the eyes, even at irradiance levels close to the MPE triggers the blink reflex. Whilst this may be acceptable a couple of times during a performance, it is annoying if it happens persistently. Observations of audiences during audience scanning clearly shows how they anticipate the scan approaching them and take evasive action after a while. One of the performances assessed during this research consisted of multiple diffraction beams passing through the audience area. The effect was generated by passing the primary beam through one rotating diffraction grating and then passing the diffracted pattern through a second diffraction grating rotating in the opposite direction. The zero order was dumped in an inaccessible area. The accessible diffracted beams were measured by the laser display company with the power to the motor drives disconnected and the maximum power into a 7 mm aperture was confirmed as about 0.07 mW from an input power of 5 W. The beams were visibly bright enough to produce a very impressive effect - the audience were essentially bathed in a mass of light rays of different colours. However, the visual stimulus was such that the beams could be viewed without blinking. This demonstrated that audience scanning effects could be used below the MPE, and indeed at a level which would not trigger the eye’s aversion response, and still remain impressive.

For laser display companies who have built up their experience with audience scanning effects it is difficult to move away from such effects. This is likely to be due to the greater artistic input required to generate impressive effects without the “easy” option of scanning high power beams through the audience. It is interesting that the US laser companies have developed far more impressive graphical shows since audience scanning has generally not been an option for them. There will need to be an investment in the capabilities of the laser radiation as an artistic medium. Some companies are combining laser radiation with other media, such as video projection (Ward 1998).

The development of the risk assessment methodology has identified the benefit of a structured approach. The methodology, taking account of the three dimensions of the input parameters can be applied to other laser applications. As has been demonstrated in chapter 8, the methodology is equally applicable to applications where there are open beams, such as medical applications, and possibly research, and to industrial applications where the laser product is used as a tool, by employees who may need to know nothing about the laser inside the product. In these applications, the culture of health and safety is likely to be further developed than in the laser display industry. However, it is still likely that the laser application will be seen as something different and very complicated to assess. The actual risks may be difficult to quantify in some applications where the technology is still being developed, such as fumes from materials processing.

In summary, the situation at the conclusion of this research work is as follows:

- many laser display companies have accepted the need to assess the risks from their work;
- laser display companies have started to appreciate the views and responsibilities of enforcing officers;
- enforcing officers have developed a greater understanding of the issues associated with staging laser displays;
- the legal situation concerning laser displays has been clarified, mainly for the laser companies, promoters and venue managers;
- all parties have gained a greater understanding of the technology used in laser displays and means of assessing actual performances;
- a methodology has been developed which guides laser companies through the risk assessment process and a means of presenting the conclusions has been demonstrated;
- taking due account of the time taken to undertake a full risk assessment, criteria have been developed to focus the effort on the key risk issues;
- the problems of pre-existing measurement methods for quantifying the laser radiation hazard have been highlighted;
- new measurement methods have been developed for quantifying the laser radiation hazard, especially during the intentional scanning of the audience;
- audience scanning does not take place at venues where the author is involved with laser safety, except under well defined conditions of operation;
- the complete quantification assessment of a show which includes intentional audience scanning is very time consuming and is generally still beyond the capability of the laser display companies;
- in general, a measurement of the static laser beam at the closest position of the audience, and comparison of the measured value with the maximum permissible exposure, gives a good indication of the acceptability of such a beam scanned across the audience;
- a flow chart to assist enforcing officers with assessing laser displays has been introduced;
- where audience scanning does not take place, the safety assessment is well within the capability of most enforcing officers;
- the results of the research have been accepted by the International Laser Display Association and are being taken into account in proposed industry-prepared international guidance;
- much of the methodology for assessing laser displays is applicable to other laser applications.

9.3 Suggestions for Further Work

The risk assessment methodology is mature and has been used on a number of occasions by a number of different people. As stated above, it will only become adopted by the laser display industry if they can see the benefits to them, and these will normally be commercial benefits. Adoption by enforcing officers should ensure a consistent approach across the UK. The methodology could be programmed into a decision support system which would be of value to the laser display company, the enforcing officers, venue managers and the promoters. It is important that the methodology does not become a "worked example", which is copied for different performances without consideration of the performance and/or venue specific issues.

The software developed for this application could be tailored to specific industries or could be generic. Such an approach may be able to attract financial support from government departments or regulators.

The existing guidance for the safe use of lasers in the entertainment industry throughout the world has generally been written by enforcing bodies and not by persons within the industry. The initiative by the International Laser Display Association to develop its own international guidance is to be welcomed. The research undertaken here will hopefully be taken forward by the industry under the ILDA banner to provide detailed practical guidance on how to undertake safe laser shows, the technology required to ensure that they remain safe, and that the residual risks can be assessed.

The development of engineering solutions to the control of audience scanning will be welcomed. There should be commercial advantages to such developments but they must take account of the actual exposure situations likely to be encountered. If the judgment of the operator can be removed then the performance should be more controlled. However, as has been seen in chapter 7 with some scan-fail detection products, the philosophy behind any control measure must be sound.

There needs to be a major investment by the industry either as individual companies or collectively to consider what makes an impressive laser show. The ability to arbitrarily scan laser beams in to audience areas for effect has stifled the development of more impressive beam effects. Audience scanning generally appears effective to a small proportion of the audience at a time, and these people are spending a significant amount of time recovering from eye exposures, even at irradiance levels below the MPE. Beams projected just out of reach above the audience should present the same impact to a much larger proportion of the audience at a time. Laser show can be impressive and the risks can be effectively managed. Hopefully, future research will not include studies of eye injuries resulting from the use of lasers in this industry.