1. General Introduction

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Laser radiation was first demonstrated practically by T H Maiman in 1960 using a pink ruby crystal (Maiman 1960). Since then many materials have been made to exhibit laser characteristics. The number of laser applications continues to increase every year. High radiant power lasers and those which utilise chemicals can present special hazards, such as the effects of fumes from the laser/workpiece interface, high voltages and carcinogenic properties of the chemicals. In many applications the laser radiation is contained by engineering design making the 'associated hazards' more important in safety terms. However, there are a number of applications where, because of the function of the application, laser radiation is accessible. These applications include the use of lasers for guidance systems for military uses, research and development, medical applications, alignment work within the construction industry and for display and entertainment.

The largest number of people potentially at risk from laser radiation are those who attend events where lasers are used for display and entertainment. The applications range from hand-held laser pointers used in lecture theatres, where the audience may consist of, say, five to a hundred people, to open air events using multi-watt lasers where the audience may run to tens of thousands.

Apart from the actual use of lasers for entertainment, by the use of beams onto screens or into the air, the display of laser products at, for example, trade exhibitions, may also present risks (from exposure to laser radiation and other agents) which may not have been envisaged by the designers of the product.

The audiences attending laser displays will cover all age-ranges and social groups. Nightclubs and discotheques will appeal to the age range from 16 to about 30. Live music will cover the complete age range, although rock and pop music tends to appeal to audiences from about 12 to 30 years. Classical music and particularly open-air concerts can cover the whole age range. Laser displays may also be included in pleasure parks which will attract family groups. The average family tends to assume that their safety is assured when attending any event aimed at them. There is a belief that "they", whoever they may be, will have taken all reasonable measures to provide a safe show. This assumption cannot necessarily be applied to some uses of laser displays in, for example, raves. Here the element of risk, with the possible availability of drugs, is potentially the attraction. The research here is primarily concerned with the safety of the family group although, of course, the same safety principles should always apply. However, the balance of risk may be less clear in some areas.

In the United Kingdom guidance on the safety aspects of lasers used for entertainment and display is promulgated by the Health and Safety Executive. Until October 1996 this was PM19 (HSE 1980). This states that the maximum permissible exposure levels (as specified in the American National Standards Institute publication ANSI Z136.1 (1976)) should not be exceeded for the public or for a height up to 3 m above where the public can stand and 2.5 m to any side of where they are permitted. The author has been involved with a number of display companies in his capacity as one of the National Radiological Protection Board's laser safety advisers. The standard of knowledge of the laser operators gives some cause for concern. Their appreciation of the safety aspects, relevant safety standards and guidance, measurement and calculation methods is limited. It also appeared that this lack of knowledge also extended to the enforcing authorities. This prompted the research reported here. During the course of the research, input has been provided to the development of new guidance.

1.2 Historical Perspective

The laser's first involvement with the entertainment industry was probably in the James Bond movie Goldfinger which was released in 1964. The laser appeared to be a helium-neon laser emitting a red beam and was allegedly cutting gold, something that is extremely difficult even now with high power

industrial lasers. Safety issues were immediately raised in this application since the implication was that James Bond was about to be cut in two by the laser radiation.

The artistic features of visible laser beams were recognised, especially the naturally low divergence, brightness and unique speckle pattern when reflected from matt surfaces (Hecht 1992). The first actual laser show is believed to have taken place in Los Angeles in 1973 (Hecht 1978). A review of the early years of lasers in art and entertainment can be found in Kallard (1979).

The rock group The Who are generally recognised as pioneering the integration of the laser effects with music. John Wolff provided The Who with a few 90-second bursts of laser light from eleven lasers during their performances (Kallard 1979). By 1977 Genesis were using lasers on their world tour (Brockum International 1977) and Tangerine Dream were touring with LASERIUM from Laser Images Inc. Tangerine Dream's tour brochure for 1978 specifies a 22 W Spectra Physics double-ended argon laser (Concert Publishing 1978). Today lasers are commonly used for entertainment either as stand-alone presentations or accompanied by music, which may be recorded or live. Systems may be very sophisticated and computer controlled or may be second-hand lasers and hand-held mirrors. The technology is discussed in Chapter 4.

The use of lasers for entertainment would initially have involved the combined expertise of artists and scientists. Lasers were initially constructed and operated by people who should have been aware of the safety issues. If they were not aware then they were likely to be injured or killed. It may be reasonable to assume that the knowledge of safety issues would have passed from the scientists to the artists but there is little evidence for this. The pioneering applications of lasers for entertainment do not appear to have involved direct exposure of people (the audience) to the laser radiation. This practice only appears when the capability to move laser beams around was developed, some time in the early 1970s. HOLOCO certainly should have had the capability to assess the safety of their early laser shows (Wolff *et al* 1977) but do not seem to have done so.

Laser games have become popular in the 1990s. Several systems are used in the UK but they are all based around a ‘gun’ containing a laser emitting visible radiation coupled with an infrared diode which is used to communicate with target areas. This application of lasers for entertainment is unique in that it can reasonably be expected that untrained members of the public will be intentionally targeting other members of the public with laser radiation.

The original aim of this research was to consider modes of failure which would result in audience exposure to the laser radiation. However, it became obvious that the audience were routinely exposed to laser radiation - so-called audience scanning. The next stage was to consider modes of failure which would result in audience exposure at levels in excess of the maximum permissible exposure (MPE) levels. An understanding of the techniques used to generate scanned beams and the development of instrumentation which could measure them was essential.

There was naturally an initial reluctance on the part of the laser display companies to any external influence on their, extremely competitive, business. However, it became clear to a number of the larger display companies who wished to work towards a greater understanding of the risks associated with their activities that there was an element of commercial interest in wanting to be able to claim that their shows were ‘safe’.

The research has been a process of mutual learning. The laser companies have been very open about the displays they produce. The enforcing officers have equally been very open about the practical issues of assessing these displays.

January 1997 saw the formation of a professional body for the laser entertainment industry. This was triggered by the presentation of, amongst other things, the findings from this research.

There is no doubt that education and training will be a major part of the development of this industry in the future. This will not only apply to the laser companies themselves but also to the laser system manufacturers, the venue managers, the promoters and also the enforcing officers.

1.3 Summary

Lasers have been used in entertainment for over thirty years and in light shows for about twenty-five years. The initial applications would have involved collaboration between scientists and artists. Safety should have been part of the normal working practices from the beginning.

The development of turn-key laser systems would have taken the scientist out of the laser entertainment framework. The use of lasers to scan audiences should have triggered questions on the safety issues. The laser entertainment industry would be working alongside other entertainment professionals who would be facing many of the associated hazards from the use of lasers. However, there is specific guidance on laser radiation hazards in entertainment but nothing which considers the other hazards.

Family groups attending events using lasers expect their safety to be assured. Ideally this requires the laser event to be staged in a professional and safe manner, which stands up to audit. The fall-back position should be enforcement of safety both within the management of the event and the venue, and the legal framework.

1.4 Aim of the Study

The aim of this study was to determine the status of laser safety in the entertainment industry and identify a methodology for assessing the risks. In particular, the following issues needed to by studied:

- current legislation, guidance and standards, and knowledge and compliance with these;
- differences of approach by the industry and enforcing officers;
- common safety issues;
- whether a methodology could be developed which would be useful to all parties;
- whether specific risks needed to be quantified.

The results from the assessment may not be restricted to the entertainment industry and therefore the application of the research to other laser applications will be investigated.

1.5 Research Methodology

An outline of the methodology for the research to achieve the aims in section 1.4 is presented below.

Figure 1.1 Research Methodology