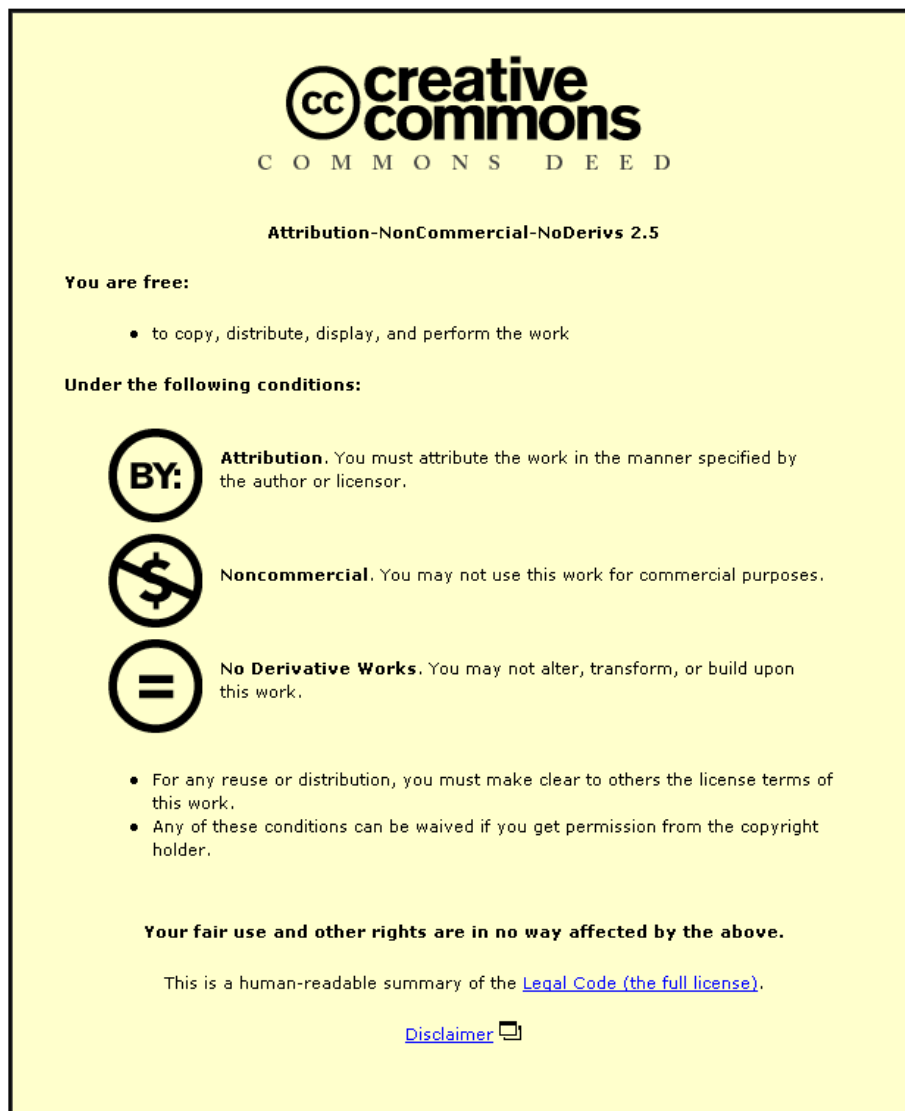
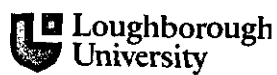


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**PROBLEMS OF INFORMATION STRUCTURES OBSCURING
LASER HAZARD PERCEPTION**

By

Paul Ducker

Doctoral Thesis

Submitted in partial fulfilment of the requirements
for the award of

Doctor of Philosophy of Loughborough University

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Abstract

This work has identified that the hazard of optical radiation still dominates laser safety standards and training. This overlooks other significant hazards, which should be identified by the risk assessment, so that safety controls can be used in connection with lasers. Laser safety standards and training information structures are obscuring laser hazard perception rather than identifying and addressing hazards with known solutions.

The literature search revealed that the hazards and solutions are known but not easily accessible in written or electronic formats. Surveys showed that despite improved communications and computer systems the knowledge was still not readily available to the users of lasers. The problem is how this information can be delivered to the general public and industries. This would enable the knowledge of solutions to improve the controls and procedures to be applied as good design, installation, use and maintenance and so reduce the number of people being injured. The information is available but is difficult to find, as search systems do not return solutions only details of goggles.

A CD of information was produced and trialled. However it confirmed that the electronic format did improve the speed of search but the CD is fixed in time and range of applications. Far wider ranges of solutions are available on the World Wide Web, but finding the specific reference is difficult due to the structure of the Internet. My hypothesis remains, that a structured search system using the Internet will make the relevant information available to a greater number of people than the present standards.

Improving access requires the location of information of web pages to be searched more effectively. Coding and listings are part of the solution but the semantic links of the search terms is the key to finding the specific relevant information. A search system using an ontology structure, which allows the sense of the word rather than just its definition to be searched for in the text of a web page, was developed. The application of ontology structure search for laser safety is the significant step of this research. This produced superior results for solutions to laser beam and non-beam hazards, in a quarter of the time taken using reference books.

Key words: Ontology, Safety, Lasers, Informatics, Structured searching, Solutions.

Summary

Although there have been no deaths directly from laser radiation, eye injuries and other harm have been caused by lasers. Non beam hazards of laser equipment have caused fires, electric shock, mechanical and chemical injuries. If people know the hazards and understand why controls or safeguards are in place, they will be less likely to be harmed. Ignorance combined with curiosity can lead to hazardous operations that can result in injury.

The use of lasers has spread to all areas of domestic and industrial life. The original control and safety arrangements were developed as they were applied in a controlled industrial environment, such as a laboratory or factory. Organisations operating in hazardous industry sectors require a superior safety culture with risk based assessments, as their field of operation has high consequential risks. Safeguards can be applied if the hazards are known or realised. Risk assessment should identify all of the hazards, such as toxins, electric shock, fumes and not separate the just the light hazard.

This thesis examines the safety culture and how it is applied, then contrasts this with other less safe users and situations. To identify all the hazards and then apply control measures to minimise all the risk, not just the light beam, is a key change to be made in the application of laser safety.

Information is available in books and via training courses but it is focused on the optical radiation issue rather than taking a holistic view of the hazard of the equipment. Access to information via computers and the World Wide Web might be quicker and can be specific, however not all knowledge is available on the Internet and it may take a determined search to find a specific item that does not have suitable links that provides easy access.

As part of this research a survey was conducted which confirmed the findings of the 1990's surveys, which were that the standards are still not understood or applied by laser users or manufactures. The general public and display operators have little knowledge of the hazards past those seen in films. This reinforces the optical radiation blinding issue

that is now legend. Improved access to knowledge of laser safety solutions is required. It was first considered that an electronic format would be a suitable candidate.

A CD of laser safety information was developed, but this was based on the laser standards and hence was founded on the optical radiation hazard. During trial and review of the CD the shortfall of lack of associated hazard identification was highlighted. Other software producers that have in effect produced electronic books have also followed this route. A structured search via the Internet will bring specific solutions that will meet a specific application.

The structured search terms were developed in an Ontology that connects not only the aspects and terms but also the meaning of the terms. An ontology has been examined for laser safety, the key was to provide the broader information links. This laser safety ontology was developed after careful review of other safety critical ontologies from other sectors. A structured approach to the laser safety ontology was based around the risk assessment, then linking the place, people and task to identify hazards and controls for specific lasers, operations places and applications.

Making it easy to find information and solutions is the key to allow safety to be incorporated in the design. The aim was to translate the knowledge and ability for the developed safety culture to deal with equipment as a whole and make it readily available and accessible. There is a wealth of knowledge for laser users and operators, which will help them identify the hazards and offer solutions, however it must be easily available. Access to the wealth of data using intelligent search engines and web robots to collect specific, relevant, information, that captures the knowledge required to address the hazards has been identified. To perceive there is a hazard/risk and then access the information and knowledge of solutions is the key aim of the information presented in this thesis.

An exemplar laser safety ontology was produced, it was then developed, tested and trialled by a range of people and that did provide an improvement of access time. Of greater significance was the improvement in quality and range of results obtained including solutions to control the hazards.

Acknowledgement

The investigations have been supported by AWE and Loughborough University although the views expressed are my own and not necessarily the corporate view of either organisation.

I have enjoyed the time during the research of the applications and types of lasers. So many people are dedicated to a particular aspect and believe in it vehemently. There are times however when they would benefit in stepping back and looking at where they are going and if they will get there safely. Being focused on your work is good but not to exclusion. Having the safety techniques and devices in place that will let you have another go tomorrow, when things go wrong today, is a wise precaution.

Publications arising from this research.

“Applying Laser Safety”

Presented at Loughborough University September 2001

“Who has the skills to deal with all aspects and all risks, associated with lasers”

Presented at Loughborough University July 2003

“The hazards - laser safety standards miss”

Presented at Loughborough University November 2003

“Problems with information structure, obscures laser hazard perception”.

Presented at Loughborough University September 2004

“Access to information and standards inhibits application of safety to lasers”

Presented at International Laser Safety Conference Los Angeles March 2005

“Problems of information structures impeding access to standards and solutions”

Presented at International Laser Safety Conference Los Angeles March 2005

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1. Introduction

1.1 Introduction.

Whilst developing lasers applications, the difficulty of searching for information and solutions to address the major common hazards was recognised. There are standards and information in text books but there does not appear to be a recognised linkage or easy access between the general safety methodologies to include lasers in a general safety system.(1) If it did there may be less accidents or lower risk of potential hazards occurring.(2) Most of the information and this research has been based in the UK but sources from the USA and other parts of the world have been used where possible to include the broadest aspects and application involving lasers and safety procedures.

1.2 Aim - To bridge the information 'GAP'.

My hypothesis after consultation in literature, training courses and many meetings with specialist in the field is that there is a GAP in the information structure between the knowledge that is available and the knowledge that is accessible and applied by the operators. This is often due to the general safety culture at the point of use or that information of safe systems is not readily available.(2)

Bridging the gap by redefining the structure will allow better safeguards to be applied in most situations. The specific hazards of laser radiation should not be allowed to mask the other serious hazards of electricity and pressure systems that are frequently part of a laser installation. All of the hazards should be dealt with from a common standpoint, as often one solution will impact on another.

There are several publications (3)(4) and proceedings (5) that provide solutions to many issues related to the safe use of lasers. These solutions do more than just address the radiation hazard, as the general safety issues of equipment cause more incidents and injuries than just radiation injuries. Most frequent incidents (4) are related to electricity,

pressurised gas systems and toxins used in the equipment. The World Wide Web has information and identifies contacts that can provide guidance to most situations of application and use of lasers.

Figure 1.1 and table 1.1 below show the GAP between radiation concerns on the island (laser safety) and the GAP to the land (general safety) that addresses all safety hazards. More robust engineering controls should be put in place to cover all hazards.

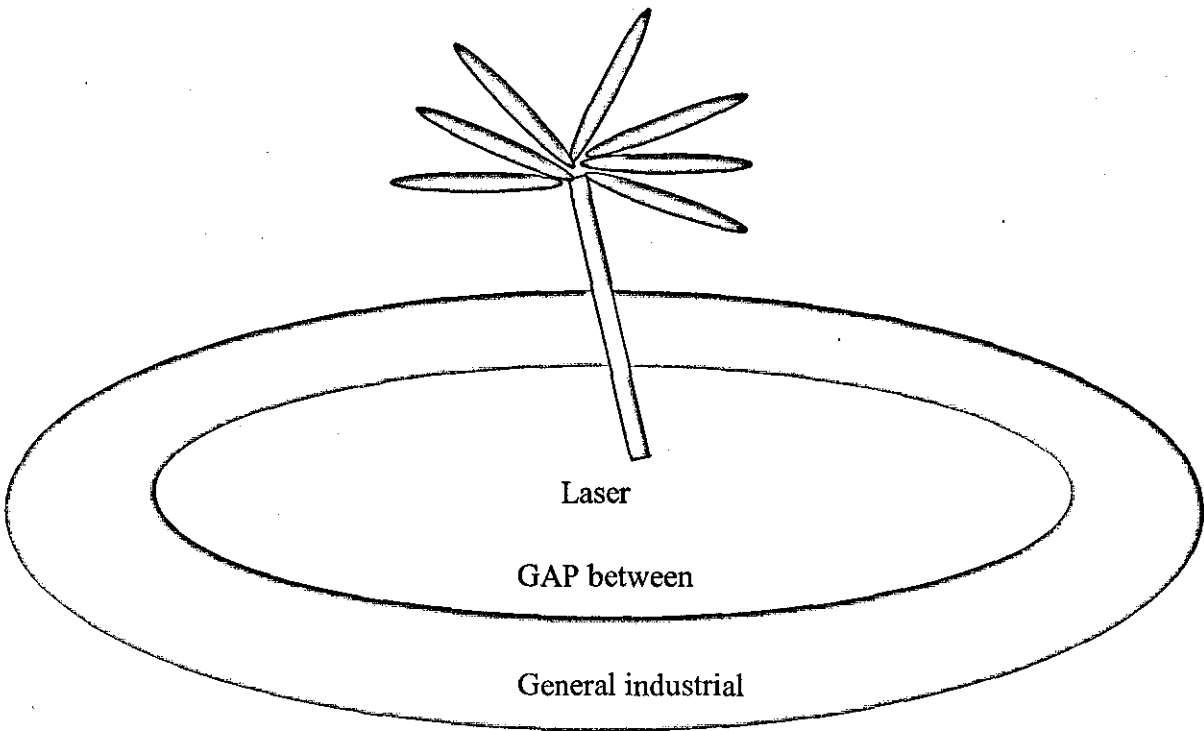


Figure 1.1 General safety and laser safety are in the same area but separated.

Table 1.1 The gap between general safety and laser safety

<u>Laser safety</u>	<u>GAP</u>	<u>General industrial safety</u>
Radiation hazard - usually defined specifically as optical radiation	Hazard	Industrial hazards - including electricity, poisons, gases.
Standards	Administration	Acts, Regulations, standards
Procedural control - PPE (Goggles)	Control	Engineering controls - interlocks, containment

1.3 Reason for research - The information is not getting to the users.

People in the laser community know of numerous incidents where lasers have caused harm. Within the laser community are the members of the UK National laser safety forum supported by National Radiological Protection Board (NRPB) and Loughborough University. This consists of manufacturers, users, researchers, consultants and NRPB staff. Discussion within this community identified that the incidents and their severity were linked to the operation being undertaken and the skill/knowledge of the user. A high power laser is less likely to cause harm due to the controls, standard/competence of the user, but any harm caused is usually greater with a more powerful laser.(3) There are a greater number of incidents of harm in the group of less knowledgeable users.(4)

2. RESEARCH METHODS

2.1 Methods of literature search, survey and development of CD.

The literature search was undertaken at general, technical libraries and the British Library. An electronic search of published literature was drawn to a short list and the text sampled. Many references had scant detail, however a few bespoke publications and journals had a wide range of laser safety information. Extensive searches of online and reference electronic sources produce some more references but the division between laser beam hazards and general safety was apparent throughout.

The previous safety surveys of the 1990's were repeated to judge if there had been significant development from the original findings of poor access to information. The surveys were developed to frame the organisation and relate the surveys to the general safety requirements through to emergency arrangements and review process. Again it was found that the situation was the same, with poor access to information due to the structure of access arrangements.

An electronic database was developed that would improve access to the available information however during development this was identified as just an electronic book

and that it is fixed in time. Further development of an electronic search system was to develop an improved framework that would improve access by improving the linkage of search terms. Several software packages were reviewed and the exemplar was trailed during development to optimise the output to address user feedback.

2.2 Hypothesis. Ontology can improve access to laser safety information.

Ontologies are structured relationship links that are used by a search engine to gather information on the relevance of text on a web page or within a document. The safety knowledge is available but often does not get to the operator, due to poor communications or ignorance of the hazard. If the safety information is available and an example of the suggested safeguards for a particular application described, with a picture, the way forward could be achieved.

Searches do not find the specific information required, but it can be found if the location is already known or substantial time is invested. Many solutions are available but are not easily accessible due to being fixed in time or not located by search. By improving the search criteria, linkage and association superior results can be obtained. Safety information for the common place hazards should be available as well as the hazards of laser light. The structured linkage of an ontology will enable this to be achieved.

2.3 Research methodology. How well developed are the search engines.

The discussions and semi-structure interviews with world experts in lasers and eye surgery (6)(7) have identified a GAP between the safety cultures and how general safety is perceived. The written text (1) (4) gives a framework to consider the laser safety aspects and why they are separate from the general approach to safety. It is unlikely that strong controls could operate for a laser if the general safety standards applied were poor.

2.4 Research and investigation to support good search results.

Many safety issues and topics are supported with information provided on Compact Disc (CD).(8) Information can be found more quickly with electronic searches but the quality of the result depends upon the search terms and how the information is indexed. Investigation revealed electronic listings and safety information but they were fixed in time and did not support semantic searches. There was good hypertext linkage but this did not identify a solution, only a range of information on a topic. Several high hazard industrial sectors have developed superior search engines that have been shown to improve the speed and quality of results. This process has been reviewed and developed to an exemplar as part of the thesis.

3. Literature review.

3.1 Introduction.

Since lasers were first invented the possibility of eye damage has been a main influencing factor on the controls applied to their use. The regulations and international standards (Z136 and IEC/BS EN 60825 series) that have been developed give good support to minimise the chance of eye and skin damage but there are still accidents each year, which are due to laser related hazards. This thesis investigates the present controls and people's attitudes to applying the good sense offered by the use of the standards to reduce the chance of a laser related accident.

There are over 20 standards (Z136 and IEC/BS 60825 series) that address specific areas of use, application guides, articles, and information available, that promote safe use of lasers. The Rockwell International website 2001-2 accident rates (4), show that the knowledge is not being applied effectively to reduce harm. There are consistently the same types of incidents where a person receives an electric shock, PPE (Personal Protective Equipment) is not worn or an errant beam enters somebody's eye. Table 3.1 below shows the number of incidents has remained constant although the number of lasers in use has increased. Manufacturing safeguards and improved reporting routes should have shown a fall in the number of incidents even with under reporting. (4)

Table 3.1 Summary of the number of laser incidents per year (www.rockwell.co.).

Year	Number of incidents
1987	9
1988	19
1989	7
1990	18
1991	14
1992	18
1993	13
1994	9
1995	14
1996	16

The number of lasers in use has increased, and thankfully the enclosures for CD (office/domestic equipment such as laser printers and CD palyers/recorders) and similar equipment does provide an engineered level of protection.(1) The failure in each incident is examined and the short falls identified with proposals to improve the application of safeguards.

The international laser safety standards and guidance are supporting documents for the general safety legislation and directives used in countries throughout the world. Health and safety legislation sets minimum levels or standards for the general case to prevent injury at work (9) and reduce risk to consumers. Individual topic areas have more specific legislation that sets standards and guidance in approval codes of practice. The motivation to comply with the requirements of the standards is a moral responsibility but mainly litigation and prosecution by enforcing authorities is the driver.

3.2 Regulation Z136.1 Standard IEC/BS EN 60825, laser safety documents.

3.2.1 How good are the present standards?

The international standards and guidance (10)(11)(12)(13)(14)(15)(16)(17) are at a level that requires prior knowledge or are aimed at those who can devote time to learning about the subject, but all too often the hazards are glossed over and the application is seen to work. People have time pressures to get the task completed, so if the laser functions and performs the task, that minimum is all that is done to provide safeguards.(18) The controls and restrictions that should be applied, are either ignored or planned after the size and alignment has been found by trial and error. (19)

The Z136.1 (20) and IEC/BS EN 60825 (21) have been developed separately from ICNIRP & CEN standards, but along a similar path in that they intend to set a minimum standard of controls. However whilst Z136.1 is legally enforceable in 10 states in the USA (it was not in step with the prevailing consensus of laser safety during the 1990s),

the British / European IEC/BS EN 60825 is advisory and guides the user within a risk assessment framework to identify and control the hazards.

The standards have expert groups reviewing them and extending the scope to cover developments such as LEDs and higher powered laser devices. The advice for the medical profession in part 8 of 60825 (22) gives details of the extent of the training and the suggested reporting structure of the medical facility where the laser is used. The advice given in part 8 of 60825 reflects the alternative approach for medical applications than that of guards and interlocks, specified for fixed industrial lasers with a brief acknowledgement that training would be of benefit to the operator.

The standards have developed in step with the development of more powerful lasers but an issue is that the applications are ahead of the training and advisory bodies that can translate the intention into suitable precautionary measures for that application. An example is the technical development of lasers that can deliver femtosecond pulses and then the exposure levels tabled in the standards being extended to this shortened time period. Business costs, time and competition often force the standards to a minimum, or even only a passing acknowledgement to the requirements. Unless the final application has the correct interlock and guards fitted during manufacture, often no other action or amendments are made on installation. (23)(24).

The GAP is that there are strong international laser standards but they are not applied, as shown by the statistics in the laser accident databases. (4)

3.2.2 How well are the Standards applied?

The Z136.1 and IEC/BS EN 60825 are aimed at industry and cover medical applications. However the military are covered by their own standards which introduce the concept of probabilistic risk assessments. The British military standard of JSP 390 1998 (25) does define controls for use of lasers during training and to protect friendly forces. However during conflicts these controls are not applicable as the laser will be part of a lethal weapon system. Entertainment applications differ as they should always meet the safety requirements and do not allow the safety requirements to be waived. The

requirement for a risk assessment approach has been introduced to the entertainment industry by a HSE guidance document HS(G)95, (26) which takes into account that the lasers can be used in the open and when there are other people about who are not likely to have knowledge of lasers, hence additional precautions are required.

3.2.3 The use of lasers in the workplace.

This practical guide has been prepared by the International Non-ionizing Radiation Committee of the International Radiation Protection Association in collaboration with the International Labour Organisation OSH68 (27). The guide has been written by Dr Sliney with support from the ICNIRP and IRPA committees. The guidance and standards are in plain language that has strong links to the IEC standards. A key difference of this standard from the others mentioned above is that there are specific duties for laser safety officers, users and occupational health and safety staff. There is a requirement for co-operation and responsibility to help make the laser use safe. This is understandable, as the standard has been written to improve the working conditions and environment of the staff that are part of the labour organisation. (27)(28).

The research paper of industrial applications by Vassie et al 1993 (24) identified that companies have had laser incidents but most were unwilling to support practical working guidelines that would reduce the risk in the future. This was confirmed in 1994 with a similar report by Tyrer (23) and again during my research which found that a more proactive approach is being taken to general safety (29)(30) but that laser safety is not being driven as fast, or linked, as many other topics.

Some large organisations and government departments have their own safety documents (31)(32) that set the standard to be met within the organisation based on the legal and research requirements. These standards may combine several legal requirements into a design and operational manual or information pack for a particular experiment or hazardous process. This usually takes account of risk assessments and competencies of staff to streamline the usually more generic statements in legislation. These usually give more practical advice to make systems safe and are often linked to a person or group who can provide support and advice to meet the level of safety defined. The advantage

of this arrangement is the standard must be met, as it is driven by the organisation and the advice is at no cost, rather than in the outside world where the costs can be reduced by not meeting the set standards and not asking for advice. The down side of not meeting the company standard is more accidents and losses that are not always balanced back to drive safety in the first instance.

The GAP is that some lasers are used open beam without appropriate controls, and that there are many instances where the standards are not taken account of due to a poor safety culture in the workplace. The GAP identified is that although the standard came into force at the beginning of 2001 it did not do anything new.

3.2.4 Outdoor controls.

The guidance notes of HS(G)95 (26), [replaced PM19 (33)] are specifically for lasers used in the entertainment industry. The guidance covers the laser hazards, associated problems and associated issues of a laser display to the public, indoors or outdoors. The quality, skills and attitude of operators of display systems vary enormously. Their approach varies from well informed and professional, able to provide an impressive display to the other extreme where they are arrogant and flout the guidance, scan audiences, not caring what the beam power is or where the public could be located. (19)

The high energy laser, in the USA airborne system, has taken this hazard to a much greater level, as the range is substantial and the aircraft could operate anywhere across the world. (3) Risk assessments (34) are now taking account of the extended range by using probabilistic assessments (35) to address the highest hazard scenarios as there are otherwise too many variables to complete the normal type of assessments. The Civil Aviation Authority has procedures in place to address the hazard of pilots being dazzled by lasers and numerous instances have been reported. (3)

The GAP is a lack of competency/inspection of many operators of outdoor laser systems.

3.2.5 Medical laser safety.

Medical applications of lasers have several unique qualities in relation to other industrial or entertainment uses. The operator is skilled, in that they are qualified and the patient, staff and operator are usually operating with procedural controls on or inside the patient. The BS EN 60601-2-22 (36) covers the special requirements of the equipment from a general medical standard. This standard is within the medical grouping, but the reference to the technical guidance is aimed at the manufacturers, covering the same area is IEC 60825-8 TR (22) of the safety of lasers products group. The information on the specific requirements for user training or practical application of the laser safety standard is in the manufacturer IEC listing, whereas the technical equipment detail is listed in the medical application area. This appears a reversal of the location of the standards given their target audiences.(37)

Some of the style of the documents relates to the date of publication, being 1999 for the guide and 1995 for the equipment specification. This does highlight the change in approach that recognises that practical details of how to achieve a requirement have been recognised and some moves made to support the users.

The GAP is that although the 60825-8 (22) standard has better information than some other parts of 60825, it is not available for all areas of application and not recognised by the users.

3.2.6 Update of IEC 60825 2001.

The IEC 60825-1 (38) was updated at the beginning of 2001 with the main changes being the classification of hazards and the extension of the Accessible Exposure Limits (AEL) tables to Femtosecond pulses. The hazard class has been revised to remove the class 3A and add class 3R, both classes 1 and 2 have been extended to class 1M and 2M to cover the use of magnifying optics. These changes have been supported by similar experimental data to that used by Z136 standard and the changes to the α_{\min} are similar to deal with extended sources in a common manner. Some reclassification of lasers will

allow higher powers to be used in communication systems, but most lasers will not be effected by the changes. (40) The other change to the AEL tables is that there are dual limits for the 400 to 700 nm range bandwidth for 10^{-3} to 10^{-4} seconds, that has to cover photochemical and thermal damage mechanism so the appropriate value must be used. The AEL tables have been extended down to 10^{-13} second values to cover the very fast pulses that are now being used more frequently. The restrictions that were applied to LEDs in the 1994 (41) version have been amended. This will allow some LEDs to be reclassified from 3B to either 1M or 2M, hence removing the controls that were originally required.

3.2.7 Reform of IEC/BS EN 60825, Z136 structure and content.

The standards (11)(21) have developed over time, as more information has become known about the eye and its damage mechanisms. The safety margins were originally larger and have been reduced during successive revisions of the standards.(42)(43) The present margins are based on research and a better understanding of the effects of frequency and pulse length. (7) As technology has improved the safety controls and enlarged the type of applications, the standards have been developed to address the issues, sometimes contemporaneously and other times in hindsight.

The standards are moving together, with an intention of harmonisation. However there still remains some discussion regarding the values and application of certain limits of exposure. The drivers for change are a mixture of legislation, technical and commercial advantage. There are many accidents (4) so the feedback is needed to develop the standards, to be more easily understood and cover the whole range of frequencies and pulse lengths. The faster pulses used are in the picosecond range, hence the standards (38)(44) are needed to be extended to cover that range. The commercial application of telecommunications has seen incremental growth and are wanting to maximise bandwidth and capacity of existing systems. This has driven the development of new systems with more powerful and cost effect techniques for the future, hence standards are also developed. (45)(39)

3.2.8 An inspectors view of laser legislation.

The perspective of a HSE inspector is that the standards should support safety improvements (46). A key point that is demonstrated by IEC/BS EN 60825-8 (22) is the practical guidance that can be provided, rather than rules, that assists understanding and therefore compliance is more easily achieved. Several laser standards are recognised around the world. However the legislation to enforce them varies not only from country to country but in some parts of the USA between States. In Europe most countries have general health and safety legislation that requires the employer to take reasonable care of employees and their health. In UK, this is the Health and Safety at Work Act etc. 1974 (9), supported by specific work place regulations such as Management of Health and Safety at Work Regulation (MHSWR) (47) and Personal Protective Equipment regulations (48). work equipment, (49).

The limits at the longer exposure can be swamped by the natural exposure of the sun or the processes such as arc welding or hot process work. This gives rise to confusion in the mind of the employer of how can it be reasonable to allow exposure from an infra red process such as hot work, but lasers that are of a lower powered in the particular instance are not allowed? As there are few HSE inspectors (46) with specialist radiation knowledge, enforcement is focused on research and development industries as well as universities. As these often have lasers being used in temporary experimental situations a safer culture, not just the standards, must develop to improve safety in the workplace.

3.2.9 Harmonisation of standards.

There are some differences between the safe levels of exposure within classes that have yet to be resolved, as they both are based on similar biological data.

Table 3.2 below shows some of the common topics that both standards include and the difference of some specific areas such as education and outdoor use. The outdoor use is addressed in a HSE document (26) in the UK but has no counterpart in other parts of Europe.

Table 3.2 Comparison of parts of Z136 and IEC 60825

Z 136 Topic	Parts		IEC 60825 Topic
User standard	Z 136.1	IEC 60825-1	Safety of laser products
Fiber Optics	Z136.2	IEC 60825-2	Fibre optics
Medical facilities	Z 136.3	IEC 60825-3 TR	Display and show lasers
Measurement	Z136.4	IEC 60825-4	Laser guards
Education	Z136.5	IEC 60825-5 TR	Manufacturers check list
Outdoor Lasers	Z136.6	IEC 60825-6 TS	Optical sources
Laser Eye Protection	Z136.7	IEC 60825-7 TS	Infrared communication
		IEC 60825-8 TR	Medical equipment
		IEC 60825-9 TR	Broad band MPE's
		IEC 60825-10 TR	Application guidelines

A key difference is that some of the provisions of the IEC are requirements of the ANSI standard either by national or State laws. Examples are the enforcement of the use of PPE and medical surveillance as well as the investigation of accidents. The IEC suggest this but it is not rigorously pursued by the enforcement agencies in Europe, as it is in the USA. This reflects the difference in litigation and attitude to safety enforcement between the countries. The Americans are more likely to sue whereas in the UK safety enforcement is more active. (7)

The standards/regulations have developed to cover the application and more technical detail over the past few years. The interpretation is no easier however with many sections and sub divisions, that require knowledge of all of the IEC/BS EN 60825 or Z136 to know which bits to apply. A revised 60825-1 standard came into force at the beginning of 2001. As they have developed, they are inevitably out of step at present. The list of items for the Z136 review meeting in 2002 shows they intend to apply many tweaks to get the standard in a more consistent form. The CDRH (Centre for Devices and Radiological Health, part of the FDA, Food and Drug Administration) has announced in (Laser Note No. 50) on 27/5/2001 that it will now accept equipment to IEC 60825 amendment 2 to be considered compliant in the USA. This will lead to an

update that is consistent with the IEC standards. The IEC 60825 has wide variations to the training required of Laser Safety Officer (LSO) and the authorising body, that the medical service have but nothing equivalent outside. The developments are to give a level of safety that can be applied to minimise the chance of injury but they are complex to put in place.

A view from a long way outside the laser community may point at the general safety requirement of Provision and Use of Work Equipment Regulations (PUWER) (49) and drive that guards are fitted, lasers enclosed, with just the last few exceptions requiring calculation being detailed in the laser standards. This would reduce the size of the documents but still may not allow the standards to be applied without specific training in laser technology. This key issue, of the difference between the general safety legislation and laser specific legislation, does not reference or embrace the general requirements for safety, rather treating the lasers as scientific instruments, almost excluding them from also being work equipment.

The GAP between laser safety specialists and general safety must be bridged because only with a holistic view can all of the hazards be identified and controlled.

The main shortfall at present appears to be the lack of definition of training for LSOs, operators and users of lasers. If there were levels agreed then this would provide a common level of knowledge of the hazards. The other link is with more general safety approach to deal with the fixed engineering controls where they can be applied, such as fixed locations in buildings, with fewer procedural controlled applications outside.

3.3 Literature.

3.3.1 General availability.

Most libraries have some books on lasers in their technology sections. (50)(51)(52)(53)(54) These are often related to computers and electronics but there has usually been several on laser technology in its own right. Public libraries the author visited had one or more books covering laser safety, or at least several sections in a

general book on lasers. (55)(56) Some books had a poor level of information, that almost amounted to “do not look at the laser or shine it in somebody’s eyes” (54). This is a start but does not address the risk posed by higher class and more powerful lasers or their reflections and the associated hazards.

Reading the books solely on Laser safety eg: (57)(42)(43) has highlighted the vast range of knowledge available and some application of safety procedures and techniques. Investigation has shown that these three authors, Winburn, Sliney and Henderson, (57)(42)(43) have the best coverage of the subject, produced in published books. Some of the books such as Winburn's details the learning points and could be the basis of a National Vocational Qualification (NVQ) or similar nationally accredited training scheme. It does take an interest and determination to find and read the information, the application part is slim and a user may either not apply an adequate solution or may miss an important consideration such as the hazard of reflections or stray beams. The useful information is not easily found, read or applied without determination on the part of the user.

There were few books specifically on laser safety and those that there are, cover aspects in a generic manner and focused on calculations rather than identifying hazards and applied solutions. The calculations are important for eyewear and to protect skin but it would be better to enclose the laser operation rather than rely on protection worn by an operator. The GAP is that the traditional literature does not deal with all of the hazards, only the specifics of radiation.

3.3.2 Specialist libraries

(IEE, Loughborough University, AWE and The British Library).

The British Library, and other specialist libraries such as those at the AWE, IEE and Loughborough University have a similar range of books and although the specific holding varied, nothing better was found than the literature found in the previous section (57)(43)(42). These libraries all had a larger selection of books on lasers and their

uses.(58)(59) The level of detail did not improve except for some specific applications such as laser ablation or some medical procedures.

In general each specialist library visited had a wide range of laser books. Subjects ranged from electronics and communications, through measurement and analysis to cutting and welding. The information in many books covered calculations, classes of lasers and the requirements of keys, interlocks and controls were well covered. The detail of solutions to enclosure problems or good practice for optical benches was not easy to find and required some prior knowledge.

The lack of details and good practice solutions, supports the requirement for training or another method to raise the awareness of the reader to look for the information and solutions. Further checking of the Internet, listings, specialists book supplier web sites and information sources such as encyclopædias, (60) confirmed that the majority of published books that provide guidance and detail of laser safety have been identified.

The GAP is there are few practical examples of the safety requirements that are widely available in book form.

3.3.3 Journals and articles. LEOS ,IEEE

Specific journals LEOS, IEEE (Laser & Electro-Optics Society of the Institute of Electrical and Electronic Engineers) (1)(61)(62)(63) and conference proceedings (1)(64)(65)(66) have yielded far more supportive, practical information on areas of activity than have been found in any other media. These articles (61) cover specific areas and some whole applications of a control or procedural technique for installations. The depth and scope of the publications do not give a complete range to cover most common applications, as the key interest for the LEOS journal is for optics and electronic applications rather than heavy power laser applications.

There are many articles on the application of techniques and devices, which include the enhancement of systems and the developments in research, but few articles on safety

aspects or systems to control the laser. Further review of articles and journals has shown that lasers are being used in a far wider number of applications of laser techniques and equipment than ever before. (67) Lasers are used in common applications such as DVD and domestic applications, which increases the chances of uncontrolled exposure if the equipment is damaged or misused.

The GAP is that these sources are specialist articles that are not easily available.

3.3.4 Laser Institute of America. ILSC

These International Laser Safety Conferences (ILSC) held in the USA have safety papers covering all aspects of lasers and their use. The proceedings for the 1990 (64), 1997 (65), 1999 (66) and 2001 (1) International Laser Safety conferences have been received and have provided a valuable source of information and contacts. They have dealt with the practical hazards and in-depth discussion of laser classification systems, including the margins of safety built into calculations. The associated hazards of ancillary laser use such as electric shock, fumes or toxins are dealt with in detail, with papers covering individual topics, such as the flammability of surgical drapes.

The International Laser Safety Conference has a wide range of world experts addressing the safety topics, rather than, as is more usual for research establishments, to only cover scientific advances. The range of topics has supported the premise that there are organisations that deal with lasers in great detail pushing the boundaries of science, size and application. The consensus is that the existing standards cover the eye damage threshold and classify lasers but do not cover the associated general hazards or offer rule of thumb guidance such as:- If the laser beam power requires protective eyewear with an OD of over five, then there most likely will be a skin hazard as well. (68)

The GAP is that there is good information but you have to look hard, It should be made more easily available, and for a wider community.

3.4 Internet.

3.4.1 Searching the Internet.

The Internet was searched for 'laser & safety' and 'laser safety' with a variety of search engines:- Google, Yahoo, WebCrawler, Altavista, Ask Jeeves, Excite, Lycos.

Table 3.3 Number of hits (in thousands) when laser safety is searched on the Internet.

Internet search engine	Returns for 'laser & safety'		Returns for 'laser safety'	
	World-wide	UK	World-wide	UK
Yahoo	13800	2100	501	55
Google	13000	2480	11700	2540
Ask Jeeves	2074	311	72	3.2
Lycos	663	590	18.8	17.6
Excite	642	37	27	1
Altavista	Only a few hundred returns			
WebCrawler	Only a few hundred returns			

There were a vast number of hits, but many are for the same Web site. Of the sites, 30% were for any safety product however 50% were for products rather than safety advice. During this research the number of sites providing advice have increased by 20%. Tens of sites (5% of total) have been reviewed to look at papers and reports in addition to many learned societies, mainly universities and laboratories. The main areas covered by sites on the Internet are eyewear protection, but there are several consultants offering support for laser safety such as :-

ROCKWELL (69) <http://www.rli.com>

LASERMET (70) www.lasermet.com

PROLASER (71) www.prolaser.co.uk

During the research the investigation has refined the search for information to specific electronic journals and large institutions Internet sites. These sources do have frequent changes and updates whereas the books and reference material only change slowly and the main developments are covered in the scientific or manufacturing press. This refined search has provided more recent information and often with solutions.

3.4.2 Advertising and training sites.

A large proportion of the sites that are on the World Wide Web are advertising products, as the commercial drive is to get to be seen by customers. There are training courses offered but again the pitch is to sell on the Internet. The more scientific and technical research sites have information about lasers and how they can be used, most are universities or Government research organisations.(5)(72)(73) There have been better links between sites in the past few years but it takes some effort to get to the nuggets of information rather than a site developed just for safety with lasers.

3.4.3 Other Internet sites for laser safety.

Over 15 specialist Internet sites were reviewed that are not found using 'laser' and 'safety' during a search. More than 10 universities (32)(74)(75) and three hospitals as well as IEC TC 76 (76) and EU 643 (77) are informative and relevant sites. The IEC TC 76 is the site of the standing IEC laser safety committee and EU 643 is of the European 1991 Eureka project to produce a laser industrial safety CD which can be sent free to laser users. There are some training guides and awareness training on the World Wide Web with a small test at the end. Most are at University sites (74) with a good section at LANL (78) in the USA. All of these sites have taken a fair amount of searching with prior knowledge and in some cases knowing it is there and not being able to access the site, as the address has been modified. It must be the case that the information is easy to find and attractive and relevant to the user, otherwise there is no point making the information available via the Internet.

The GAP is that the information should be easy to find and ready for the users to use, subdivided to the user groups, covering all safety issues associated with those lasers.

3.4.4 Eureka 643 Internet site, industrial laser safety.

An international group (The EuroLaser University Enterprise Training project Partnership: 'Safety in the Industrial Application of Lasers' (Safety INDAL)) was established with European grant to produce a guide to 'Safety in the Industrial Application of Lasers (1991 – 1996)' (77) information for industrial users, EU 643. It provides a unique and useful but incomplete reference source. The document is available at a temporary Internet address (77) however there are no short links from search words, such as "laser safety" yet. The picture and graphs with hypertext links between sections are an improvement on the standards but at 150 pages and approximately 75,000 words, it is a long document. This is still more of a text book than a knowledge based system or computer aided learning (CAL).

The Eureka text has six main sections:- Radiation, Gas and fumes, Machine safety, Risk assessment, Training and education and Standards. The draft information that is intended to be published in CD format is good but it can only help people when it is completed and they get a copy to use.

3.5 Laser training courses.

3.5.1 Laser training courses.

The levels of training and test are linked to the level of operation at the workplace, a user, operator or supervisor, (laser safety officer) is often quoted. Some of the minimum requirements have been defined in IEC/BS EN 60825 and similarly in Z136.1. The requirements use phrases such as knowledge or awareness when they should cover the application of the knowledge in a practical situation.

There is another key point in the area of knowledge and application depending on how it will be applied depending if the person is a user, manufacturer or maintainer, as the separate groups face different hazards and have varying responsibilities in law. There is a range of training courses available that may meet these legal requirements for training.

3.5.2 Awareness training offered and the level of competence.

There are more than 10 courses on offer, usually by consultants who will train staff at a company or a group via a training agency such as SIRA (79) in the UK. More detailed training courses to LSO standard are few and very specialised.(80) The courses that are aimed at training people to take on the role of LSO, often attract people who have a knowledge of lasers or are aware of the laser hazards. These courses do not get to the large majority of people who have a laser that is part of a process or often are unaware of the laser within a system. There were a few courses for operators such as the BTEC (Advanced and Intermediate) Award in Machines Technology at Loughborough College, and some large organisations (MOD, Shrivenham, LANL) provide their own internal user and operator training /awareness.

3.5.3 Requirements of laser training courses & levels of competence.

It would be true to say that other training on specific laser and more complex arrangements would warrant training but the LSO must be able to deal with all of the arrangements and the intermittent measures that are likely to occur while a laser is being commissioned or modified. Hence LSOs should be able to address these changes or know to seek further information.

The levels of training and accreditation vary according to which source of standards or training module you take. Some Universities have online information and test sheets that an operator can log onto and answer questions that will provide awareness information and a scoring system that will check that the information has been understood. There are some better, more detailed online information and tests available at the LANL (78) and the Eureka 643 sites (77). These have to be known of, as they are

not found by searching for 'safety' or 'laser' on the Internet. The graphics are good and the language suitable for a person starting but only to explain how to stay safe if the correct engineering and procedural controls are in place. It relies on the LSO providing the correct eyewear, not just the person using it in the appropriate area.

The training and learning should be intended to take a person without the necessary knowledge to a level where the knowledge gained is sufficient to allow them to work safely or to recognise danger and stop. There will always be a range of skills and knowledge, which must be recognised, and the scope or speed of the training adjusted to support all of the people involved. During a training course the tutor should check understanding and answer questions. However the CBT training has to follow a methodical approach as the pupil may not know what question to ask or how to phrase it, unless they have some broader knowledge of the topic.

Once a person has attended and passed the training test, their knowledge level will fall if they are not refreshed or dealing with topic on a regular basis. Many refresher training course cover the basics and update new legislation or technology in an overview of the topic. This gives some confidence but seldom proves that the person is competent to continue with the responsibility of, say, LSO duties. There are several training courses provided with the UK but there is not a national standard to be met or accredited through a professional body. C&G (81), ETMA(82).

3.5.4 What training do the standards require? Retraining? Competency?

BS EN 60825-1: 1994 (21) section 10.10 requires that for class 3 and 4 lasers some minimum training must be provided to avoid danger. The training should be to an appropriate level and may be given by the manufacturer/LSO. Training should include :-

- familiarisation with the equipment,
- hazard control procedures,
- PPE,
- accident reporting procedures, and,
- the bio-effects of laser radiation upon the eye and skin.

This training is suggested as a lecture of 4 hours and adds that it is not sufficiently detailed for a LSO. This is a minimum requirement to recognise the hazards and avoid danger. It is a start to look for short falls or hazards that may exist with the laser related equipment. This should be supported with future guidance that has been produced in other standards (79) but still is only avoiding rather than minimising hazards and linking to other H&S risk assessments.

A guide for the control of laser hazards by The American Conference of Governmental Industrial Hygienists 1981 (83) requires:-

- Personnel who may be exposed to laser radiation should be considered regarding; maturity and general level of training and experience of laser use.
- Outdoor class 3 used for surveying and levelling.
- Only qualified and trained employees shall be assigned to install, adjust and operate laser equipment. Proof of qualifications (operator card) of the laser equipment operator shall be available and in the possession of the operator at all times. That person may obtain this operator card from a representative of the manufacturer when the operator has completed a minimum of one hour training in the safe use of that equipment.

The update now includes a specific reference to retraining requirements. Development of non beam hazard training requirements; to be developed in conjunction with section 5 of Z136.1 on training in the basic of laser materials processing.

The requirements have developed since BS EN 60825-1 in 1994 (21) that required hazard evaluation, training but no LSO, through to IEC/TR 60825-14 (84) that was published in 2004 requires risk assessment, information and training, and a competent person to carry the LSO duties. Both of these standards are far short of the PUWER 1998 (49) or EN ISO 9000 (85) requirements that include risk assessment, information, instruction and training, a competent person to supervise plus controls on retraining after changes.

The EU 643 working group established that the level of training courses available in Europe vary considerably and calls for a common standards and level for training. The output from the working party considers the effectiveness of styles of training and the information available in CBT format and its suitability. Appendix 5.6 of Eureka 643 (77) details the competency levels for the LSO, user and awareness for other persons, that is similar in level to the three levels proposed in this chapter. The use of a third party to provide support such as a consultant is highlighted as a cost-effective method of obtaining specialist support rather than using internal staff.

What levels of competency are required for a LSO, user or operator following NVQ accreditation as the NVQ's are divided into the following five levels?

1. Foundation skills in occupations.
2. Operative or semiskilled occupations.
3. Technician, craft, skilled and supervisory occupations.
4. Technical and junior management occupations.
5. Chartered, professional and senior management positions.

The last three levels are appropriate and of sufficient competence to cover the laser safety issues as they are at the same levels as suggested in the Australian Defence Forces training programmes. (86). There should be three common levels of safety competency for lasers; awareness, user and engineer that may have several competency standards within each level depending on the scale used. Over the past two years the Society for Radiological Protection (SRP) (72) has achieved NVQ accreditation for its level 2 through City and Guilds awarding body and are now working on levels 3 and 4. These levels are the same as the Australian Defence Forces training programs. (86). In the USA the special interest group of IH/OS (83) have requested that the USA Department of the Environment support accreditation of the LSO training, as there is no certification from a professional society for LSOs. The certified laser officer program is being established by the Board of laser safety. (69)

3.5.5 Specific laser safety training courses

Loughborough University is one of the few places in the UK where training for LSOs is offered. The others include Defence Evaluation Research Agency and National Radiological Protection Board. More general laser safety training courses are offered by 5 or 6 training providers across the country. All have a good structure and teaching staff, but are pitched at a minimum level to meet the general industrial situation.

3.5.5.1 Loughborough University/NRPB Laser safety officers course.

The LSO training is over 5 days and starts at basic physics and covers many different applications with time to discuss and examine individual cases and applications. The training includes measuring a laser output and calculating the correct optical density for protective eyewear, visits to see some large lasers and the controls and interlocks that are in use.

The LSO training is refreshed with a one day seminar once a year that covers developments in laser technology and particular incidents or developments as well as being an opportunity to talk to others to solve a problem or identify a solution to a laser problem.

3.5.5.2 SIRA. (Laser safety in Industry and the laboratory)

This one-day course covered the relevant parts of legislation and some applications. It was suggested by one speaker, who is a specialist Consultant, that the people on the course may wish to buy the expertise, as a cost effective way of acquiring laser knowledge rather than attending courses and still only seeing a few situations. There are some merits to using a specialist Consultant, who has seen many systems and has an armoury of solutions that could be applied to a particular situation. There is the counter issue that the consultant may not have seen a laser of a particular type of in that particular application before and not be able to provide a solution. (67)

3.5.5.3 Rockwell Laser Industries, USA.

Their training institute has run for since 2000 and the courses have been developed to meet three levels of complexity. There is an introductory level, to provide a solid grounding in lasers and optics for candidates with limited background knowledge, an intermediate level, where the basics are developed in greater depth, and an advanced course to enhance those attending with a breadth of knowledge to be proficient. The three levels then focus on specific areas such as industrial use, optics, measurement, for outdoor use and medical.

3.5.5.4 DOE laser safety training in the USA

The following laser safety training courses are being run at the individual sites and do raise some issues, as they are not delivered to a common standard or format. Table 3.4 highlights the differences in time allocated to training and refresher period.

Table 3.4 Comparison of training and refresher period.

Location	Training type	Refresher period (years)
Argonne	Two-hour classroom	2
Brookhaven	Web-based	2
Jet Propulsion	Two-hour classroom	2
Los Alamos	Web-based	3
Lawrence Berkley	Three-hour classroom	3
Lawrence Livermore	Web-based	5
Sandia	One day classroom	3

3.5.5.5 Laser materials processing course. (Loughborough College)

The Loughborough College in Loughborough that has links with the university training group, did offer BTEC (Advanced and Intermediate) Awards in Machines Technology and NVQs in Laser safety training, that ran for a year and were the only national laser

safety related qualifications identified. The three levels of competency are commonly used within HSE legislation and guidance to identify suitable levels. The three levels have been taken as one of the design parameters for the safety CD that is covered in this chapter and is part of the further recommended work.

3.5.5.6 Laser safety training in the Australian Defence Forces.

An Australian research study (86) outlined the training requirements and three levels of competency for laser safety arrangements in the Australian Defence forces. (86) The levels are for LSO, laser user and awareness for people working near lasers. The laser safety standard AS/NZS 2211.1:1997 (87) is based on the IEC 60825-1 (88) but they have set levels and described the interactions and responsibilities for the three levels. The arrangements are the result of over ten years experience of applying the system. They also address the question of how much experience is needed to take on the responsibilities.

The paper makes the case that the applications can be over a wide range and part of the responsibility is to realise when you need help. Another strong point made is that the training should balance between the radiation hazards and the other major hazards such as electricity and fumes. The attendees are tested at the end of the course and comment is made regarding the need to perform calculations, as it may be that elimination is preferred in most cases. This may be a strong model to build on, that could be used as the UK standard for the LSO NVQ accreditation.

3.5.5.7 Large organisations in house training by LSOs

The training is often one off and no refresher course to raise awareness is given. The GAP is there is not a nationally recognised training course and syllabus that can be followed which would identify an achieved competency. The Loughborough University course is a good level for LSOs but there is a need for a shorter version that will impart enough knowledge to the operator for them to know that there is a problem, should one exist.

The courses should be such that they will be recognised throughout Europe, although they would need to be accreditation by an internationally recognised body. Laser safety has few training groups and poor visibility amongst users and in industry. Better training and information should reduce the severity and number of eye strikes. (77)

3.5.5.8 Training by Consultants.

Training courses provided by several consultants were considered including:- NRPB, Lasernet, ProLasers, Bioptica. They have a wealth of knowledge and provide advice, often for a fee and may not be included in design reviews that enable equipment to be designed safely as well as maintained safely. It is often more difficult to add safety to a system rather than engineering it during manufacture. The consultants are called on to offer specific support or could write an approval (licence), once a system is examined such as a laser light show or installation in a factory.

A common failing is to not realise that during maintenance the interlock and safe guards may be removed or not operate in the normal way that may put staff at higher risk. Some move into the area of solutions to specific problems but there can be so many combinations that there is a limit to the number that can be covered and there could be more effective method if there are several installations or lasers in one location. Several have advice or guidance on the Internet that can help a person decide that they do have a problem and should seek help.

If you are not trained to know what the laser safety related issues are or the interactions in a laser system, a checklist can only go so far to guide a person to look for hazards. If the person is experienced or has seen the specific issue or a related arrangement then the shortfall or risk associated with the process, can be examined and control measures applied. If you do not have the experience or have not interpreted the guidance to examine a system for shortfall you will not identify the deficiency.

The GAP is you need to know there is a problem to then ask for help.

3.5.5.9 Internet online laser tests by universities/laboratories.

There are more than six training software listings on the Internet at various locations, usually on university sites. (73)(74)(78)(89)(90)(91) They are mainly aimed at awareness level for students who will be working with or near lasers. Some support lectures and other training courses but all skim the surface of the hazards and control measures. All need to be part of a managed laser safety structure within the organisation. There is some feedback monitoring in the government laboratories that check staff have attended and passed the training before they are allowed access to lasers, but this is not foolproof. There is at least one laboratory that has moved back to lecture rather than Computer Based Training (CBT) because of the concern regarding litigation for inappropriate training.

3.5.5.10 Summary.

There is a need for a national accredited course for users, operators and LSOs. Once accredited it can be maintained by either CPD training or a refresher training course. The drive to get the necessary agreements and support should be from the Government through the NRPB to meet HSE requirements to satisfy the H&S requirements of legislation. A training syllabus should be produced and endorsement gained from the NRPB and the HSE, which would then make the training an industry standard to measure and compare with other courses to ensure a minimum level is achieved.

3.6 Previous Surveys

3.6.1 Survey of the safety precautions in place at laser manufacturers.

There have been two surveys (92)(24) undertaken with support from the Science and Engineering Research Council with assistance from the HSE. Both identified shortfalls in the approach to laser safety in the laser manufacturing industry. In both cases there was a high level of laser incidents and it was recognised that establishing a safety code would help reduce incidents, but only a few manufacturers would support establishing the framework for guidance. (24)

The reports were both published in the Journal 'Optics and Lasers in Engineering' which has the laser industry as its target audience, the second report showed little improvement. There have been several initiatives from the HSE during the past few years that are aimed at improving the health and safety arrangements and systems at work. The surveys that have been undertaken show if there has been any improvement in the safety provisions of laser users in manufacturing over the intervening years. Data from the Rockwell database indicate that the position has stagnated over recent years.(4)

3.6.2 Questions asked in previous surveys.

The findings of the surveys had several aspects of concern. For example one in ten of the companies surveyed were not aware of the current laser safety standards, with one in three finding that standards were not readable or easily understood.

The laser manufacturers should be aware of the laser standards and how to apply them as they have duties under the safety legislation. The 1990 survey (92) had a poor response to the four questions asked, which were:

a) Did they have a laser safety officer?

The survey found the level of LSO appointments had risen from 46 to 57 % at the companies that require a LSO as they operated lasers greater than class 2, as required by the standards. This is a small improvement in the number of LSO appointments but is still only about half of the number that should be appointed. The case was put that the manufacturer did not use the lasers so did not require a LSO. However, they often tested or demonstrated lasers which put them in the 'user' category that requires the appointment of a LSO.

b) Were they aware of any laser safety standards?

The standards in place at the time covered the radiological hazards but with little content regarding the associated hazards relating to lasers. The enforcement was, and is now, through the Health and Safety at Work Act 1974 (9) and the PUWER regulations (49)(93). There are a plethora of H&S standards (9)(93)(94)(95) and requirements placed on employers, many written in legal or all embracing terms that require H&S training to understand and apply. Given this vast range of standards and weight of information, the laser manufacturers may have well felt that they understood the requirements of their business and diminished the requirements of the standard that they felt affected them in their topic of expertise.

The manufacturer has a duty to provide information to the user under BS4803:83 part 2 (96)(97) and later PUWER regulations (49). How can this be done if the manufacturers own knowledge of the requirements of the standards is poor and not followed? The survey did suggest that a working document that presents a practical guide to laser safety would be of benefit and assist understanding. Some work has been started towards this, but the standard revision procedure is a long process.

c) Did they have any internal guidance for laser safety in the company?

Often companies had internal guidelines. When asked if they would use independently produced guidelines 66% said they would use them and they were willing to help draft

common guidelines for the industry. However 33% did not have any guidelines and were not interested in developing practical guidelines.

d) Did they take any other general laser safety precautions within the company?

Interlocking, shrouds and appointment of a LSO were among the precautions 66% of the companies took, but only 20% took further precautions such as training personnel, eye examinations and designated laser areas. The eye examination is often undertaken to address the legal aspect of pre and post class 3 and 4 laser use rather than good sight as is now being advised. Training and guidelines are ineffective if they are not applied, which follows the reluctance to issue laser safety instructions to customers, although this is driven by HSAW Act 1974 (9).

The conclusions of the 1990 paper (92) suggest that a more readable format for the standards with increased awareness should be promoted through the manufacturers and suppliers. Better information and training in the companies and suppliers would improve awareness of the hazards and help reduce the adverse incident rates.

3.6.3 1993 survey

The second survey (24) found similar problems to the first and could find no evidence of improvements in the intervening years. The baseline for the survey had been developed from the previous survey of understanding the standards to developing a technique or methodology to improve the assessment and precautions applied to the lasers.

The starting point was that the then IEC/BS EN 60825 (12) was essentially based on biomedical threshold exposure limits for the eye and skin that did not address the practical hazards of the surroundings and associated equipment. The British Standard had become the de facto working guide but a practical laser safety programme was sorely needed. The survey chose to focus on the manufacturing sector as they were deemed to be the most aware of the requirements.

The findings showed that only 50% of the companies that were required to have a LSO had one appointed, and 33% of organisations reported that the standards were unreadable. This was the same response as found by the 1990 survey, so an attempt to assemble relevant laser safety information into a database was assessed, but had too much complexity as nearly every laser had its own safety situation.

A knowledge based system for laser safety assessment was proposed that would gather the details of a diverse range of technical areas and other issues such as the human interface to provide support of a systematic approach to address the hazards.

3.6.4 1994 survey

A further survey was undertaken by Vassie et al 1994 that examined the needs of the community in more detail. This survey was a programme of structured interviews of laser manufacturers, users and inspectors in the UK, which formed the benchmark data for laser safety awareness at the time. (24).

A key finding of this survey was that 80% of the representative sample have experienced problems in understanding and implementing the current standards relating to safety. A case has been made to draw the practical safety advice together in a form that can be easily accessed, understood and applied by the range of laser users. The present information is in a fragmented form in standards, books and technical publications.

Some of those interviewed had poor knowledge of laser hazards and appropriate control measures. However, more concerning is that all of those interviewed repeatedly highlighted the issue of difficulty in interpreting the laser safety standards. A solution is needed to meet the user requirements to have quick access for experienced users while providing sufficient support for those new to the topic or particular application.

A computer based advisory system was proposed that took this issue in two stages: laser type and its use; and the associated or consequential issues raised by the process or application. The laser beam, power supply and standard environment can be addressed

from a generic assessment. This assessment can then follow on with the specific application by adding further conditions or constraints such as fumes, access, and interfaces to other systems. This allowed a database of the hazards of several types of laser to be assessed that would always have those associated hazards, the database could then be combined with information on the hazards relating to the beam delivery system before the final interaction with the process.

This suggested expert system approach would provide a list of hazards for the user to assess, although it would still require some degree of knowledge to effectively apply the safeguards so they did not interfere or defeat each other. The computer program was to be text based and have hypertext links to provide quick connection between relevant parts. This approach allowed amendments to be made and to link alternative parts together for certain types or applications of lasers. The Eureka 643 Handbook on industrial laser safety (77) has some of the features that were defined by the survey, but it has not been widely circulated.

The more recent surveys confirm the findings of the earlier surveys, in that the standards remain difficult to understand and most laser applications have some specialist parts of the laser process or application. The following surveys of this study were conducted to investigate how well the standards are understood and applied. As even if the standards are read and understood they are not always complied with. Is it that the safeguards are still not understood or that they are not engineered into the systems during assembly and commissioning?

3.6.5 Manufacturers' technical information & maintenance manuals.

Investigation of the common types and support by manufacturers of laser systems has been a part of the investigation of this study. The survey of installations and groups of users included manufacturers. This provided an opportunity to assess the support that is provided and how effective the solutions are to the customers and whether solutions are risk based or best guess methods.

Examples of user handbook and maintenance instructions related to safety have been requested but there has been a poor response. Most will provide products with technical support if requested but this is charged for at a high rate. The examples of manuals and instructions that have been obtained are either very limited in detail or require extensive previous knowledge and relate to operational modifications to adjust the performance of the laser rather than maintaining or servicing the equipment.

Safety information is difficult to acquire even on products such as goggles. The standard sales leaflets are available to choose and buy, but more in-depth details regarding bleaching or protection from other hazards such as solvents or flying objects, are often not available.

The aspect of commissioning and service were checked as these were the times when controls might be modified and additional people are involved. Particular installations appear to be supported by the manufacturers alone but then costs are minimised and often the laser is a component in a process and the final arrangement is not considered at the design stage.

The GAP is that there is insufficient information provided to the user to assess the hazards of use, service or maintenance of the laser and its associated support equipment..

3.7 Adverse incident and accident databases.

3.7.1 Introduction.

There have been accidents for as long as there have been lasers powerful enough to cause harm. The precautions to prevent injury have been known for a long time. The knowledge of how to prevent injury is the first step to actually preventing harm. There are many occurrences of accidents where a slip, trip or failure of equipment, allows an errant beam to cause injury. However all too often the injury is caused when a powerful beam is operated in the open, and a person has insufficient personal protection.(98) A typical example is range finding or target acquisition on a range. It can happen that

service personnel are not told of the hazard or errors are made in the targeting of the laser that is being used. (3) To date, nobody has been killed by the beam. There have been some deaths from associated equipment such as electricity, fire, poisoning and crushing. The most likely injury is an eye strike. (3)(4) Some injuries are minor and almost not noticed. Others are quick, painful and devastate the person's life. The incidence of skin burn are less frequently reported, as people working with beams of this power take some precautions and the burn, if minor, soon heals.

The following sections review the information from adverse incident databases of laser incidents over many years. The analysis highlights the common factors and that the number of incidents remains constant.

3.7.2 Rockwell laser incident database.

The reports show the range and number of reported incidents. This is the tip of the iceberg as 90% of the incidents are not reported, (18)(92) but demonstrates the range. Following each table is figure that shows a descriptive analysis of the groups, frequency and number against time of events. The occupation of those involved is often research based and over 50% are likely to be aware of the hazards of operating a laser. (99)

3.7.2.1 Most common Laser type producing Laser Related Incidents.

Table 3.5 This relates the % of incidents with types of lasers

Laser Type	Percentage
Nd:YAG	29.7
Argon	20.5
CO ₂	12.8
Dye	9.9
HeNe	7.0
Ruby	6.1
Unspecified	5.5
Do. YAG/Ruby	3.7
Other (HeCd,Cu..)	3.7
Diode	1.1

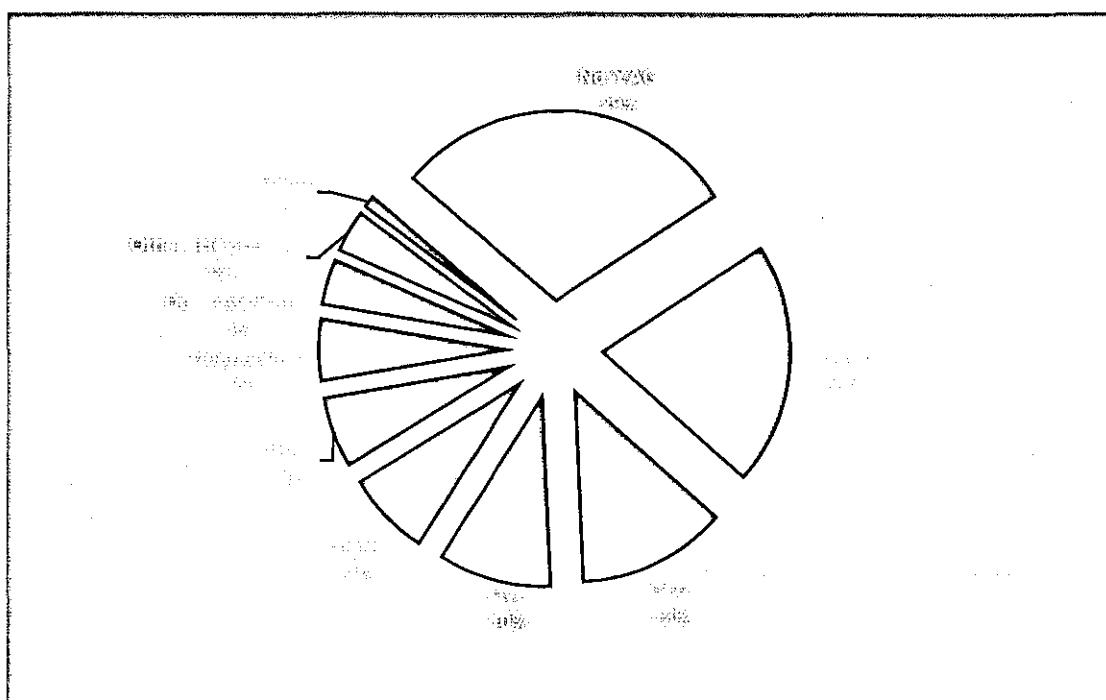


Figure 3.2 types of laser by % of incidents.

This is linked to the number and power of lasers in use. The frequency will dictate, to an extent, the type of injury or amount of eye damage. The number related to diodes lasers is likely to rise as they are becoming more powerful and less complicated to use, and hence will be more popular.

3.7.2.2 Occupation of Person Involved in Incidents

Table 3.6 Relates the incident to the occupation of those involved.

Occupation	Percentage
Technicians	21.3
Scientists	17.6
Patients	12.9
Plant Workers	10.7
Doctor/Nurse	9.2
Students	8.4
Spectators (Light show)	4.8
Laser show operators	4.1
Pilot/Military	3.3
Equipment	3.3
Field Service	2.6
Office staff	1.8

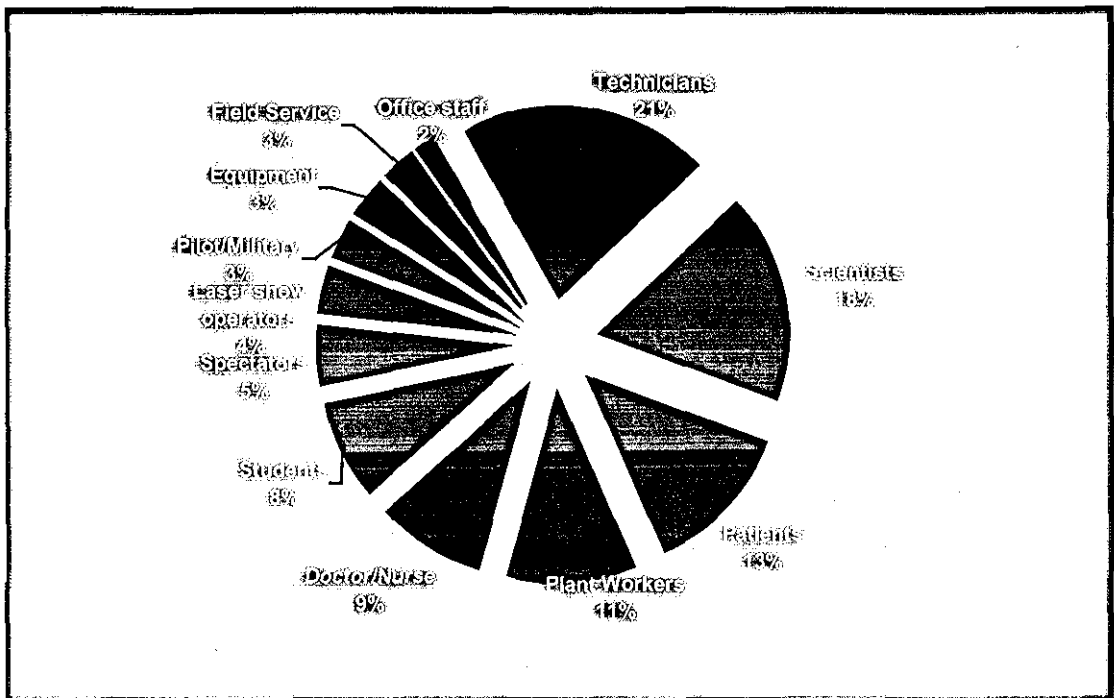


Figure 3.3 Occupation of people injured by %

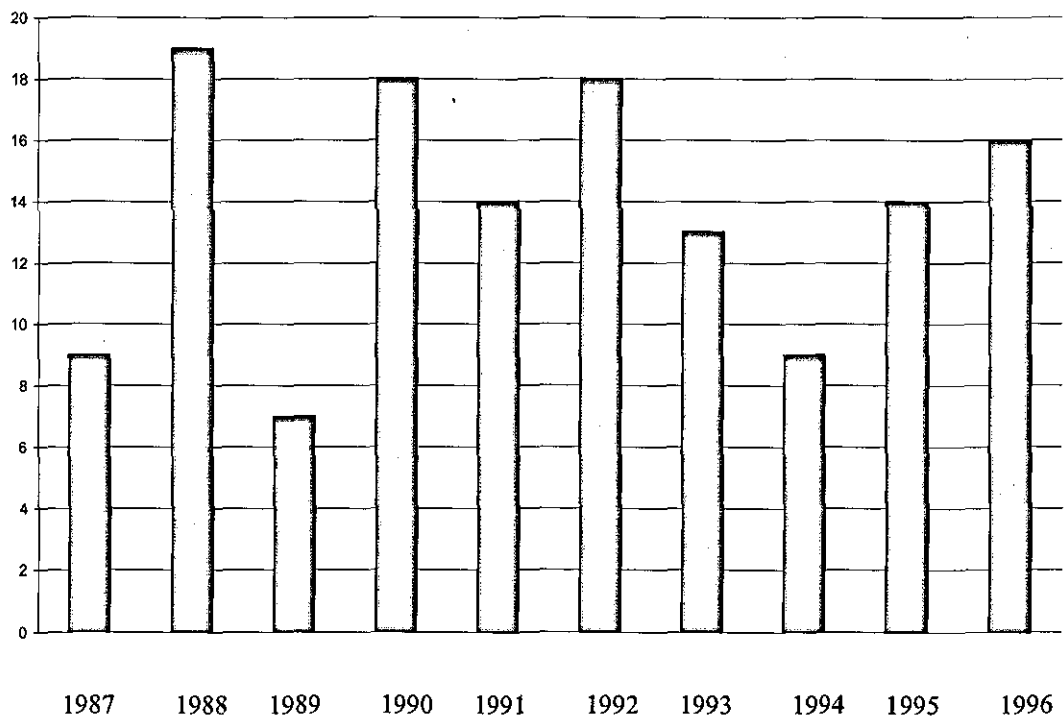
The high number of technicians in the database relates to their servicing and maintaining the lasers when normal operations have been suspended. Scientists' experiments often have temporary arrangements that provide more opportunities for adverse incidents. The most concerning group to be identified is patients, but when reviewed in more detail, they were during operations when the person was under anaesthesia and gases were involved. This then questions if the medical staff could do more to avoid adverse laser incidents. If the laser is cutting and body gases are present, an alternative technique might be more appropriate.

Table 3.7 List in order of the most frequent cause of injury. Most significant at the top

- 1 Unanticipated eye exposure during alignment.
- 2 Available eye protection is not often used.
- 3 Equipment malfunction causes many unwanted exposures.
- 4 Improper methods of handling high voltage lead to severe shock and even death.
- 5 Protection for non-beam hazards is often lacking.
- 6 Improper restoration of equipment following service frequently causes undesired hazards.
- 7 Incorrect eyewear selection and/or eyewear failure are frequent causes of unwanted exposure.

In table 3.7 the two highest numbers of adverse incidents, alignment and not wearing available eye protection are likely to be the result of failure to follow procedures or other human factors, which supports the advantages of using engineered controls rather than procedural controls.

Table 3.8 Summary of the number of adverse incidents per year.



The chart above shows that the number of incidents per year has remained more or less constant. The number of lasers in use has grown over the period hence a reduction in the number of incidents related to the number of lasers is appropriate.(6)(7) Although the number reported is similar, the causes have changed. This indicates a change of use or increased awareness in some sectors and development of awareness in others.

3.7.3 Key incidents and highest number of occurrences.

Improvements have been made following each incident. The issue of cooling the fibre optic has been addressed with modifications to the equipment and hence fewer incidents now occur. The non-use of eyewear, even when it is available, remains an issue. Engineered solutions are required as part of the equipment design (79)(47) and should

be chosen before resorting to PPE. Some of the incidents could have been avoided if engineering controls had been in place rather than just procedures. Some of the other incident types are due to lower awareness of the hazards and that eyewear should be worn whilst in the NOHZ area. The list below relates to the more frequent adverse incidents followed by comments on the improvements made to the systems and procedures.

Table 3.9 List of group of adverse incidents by type. (number from RLI database(4))

- 12 Incorrect cooling of fibre tip causing gas embolisms; now improved cooling is used.
- 11 Laser eye wear was available but not used.
- 3 Pilots receive eye strikes.
- 2 Electrical fault with laser equipment.
- 1 Opened shutter.
- 1 Defeated interlocks.

There are high numbers of incidents in hospitals that are related to the exposed beam and difficulty in applying engineering controls. If the surgical laser beam is used to remove or cut away tissue, injury can occur if the firing switch is operated by accident or the delivery head is not in the correct place. Accidental exposure could be reduced if the controls were better guarded or had an additional shutter as well as the two stages of power up, (standby and lasing). This still requires discipline in use between lasing as sometimes lasers are left on standby while other procedures are completed and the firing switch operated by accident. The additional shutter could be controlled by a person other than the person operating while the other procedures were completed.

The national laboratories and medical establishments have a good reporting culture as they are more closely linked with the government with fewer commercial constrictions that may suppress the incidents.(3)(4)(69) The number of incidents listed is typically the tip of the iceberg (3) (99) and there are possibly 10 or 20 fold more incidents than reported. This ratio is in line with other safety reporting ratios of incidents and injuries.(69)

3.7.4 Brooks Air Force incident database.

The incidents reported in the Brooks Airforce database are nearly all additional to those reported in the Rockwell database. The Brooks Air Force base incident database has 85% of its total number as different incidents than those listed on the Rockwell database. Both databases are a similar size with 15% of the incidents that are reported common on both databases. This illustrates, by considering each database in isolation and then comparing the incidents that are not repeats of the same event, that access to information can significantly change the perspective on the number of incidents and the reporting culture of organisations.

The more frequent incidents listed are related to not using eyewear. Many incidents are of personnel looking at, or being illuminated with, range finding military lasers. There are two other main issues. Firstly, many of the incidents are in laboratories, but no further details were provided in the original listing. Secondly, several incidents were as a result of warning signs, sounds and procedures that were ignored, even though the staff had knowledge that the hazard level was increased in that area.

3.7.5 More recent incidents at USA DOE sites.

This final database is from the USA Department of the Environment with reports mainly from the National Laboratories. The training and LSO support within these laboratories must reduce the risk of incidents, although the reporting culture has revealed a higher number of incidents compared with non-government organisations.

3.7.6 Reporting of accidents and incidents.

A growing number of incidents (3)(66) reported are due to distraction or dazzle as the number of incidents of the use of laser pointer used mischievously has increased, often with severe results as, for example, vehicle drivers have crashed and caused severe physical injuries. (4)

At a lower level of incident power there are some near misses reported in the large organisations (3) (4) that have developed a superior safety culture. These organisations have the benefit of recording near misses that allow steps to be taken to avoid serious accidents. Recent statistics show the same numbers and type of incident. (4)

The number of laser incidents over the past years is still at a steady level, rather than increasing as more lasers are used or reducing as more people become aware of the hazards. (69) Most of the accidents reported are of higher profile incidents such as scanning of aircraft and vehicle drivers with laser pointers. These often have consequential injuries, although no long-term eye damage has been reported. The low numbers of reports in comparison with other more violent crimes or injuries that dominate the press reports is due to the high profile of those injuries. (46)

The detailed reports of laser strikes can only be found from company or internal organisation incident reports that are more difficult to access.(99) There are a consistent number of eye strikes reported each year, the types and groups depend as much upon the reporting culture as they do upon the severity or frequency. Most people would not know they had had a minor laser eye strike and would just accept it as a bright flash of light. Even some of the more serious eye injuries are not reported as they are caused when people are breaking other rules in the workplace. (46) The reports are from a broad cross-section of organisations, from a few staff to thousands and from research through industry to medical applications. During the survey, account was taken of the existing culture and accident reporting arrangements of an organisation, as this will affect the approach and style of feedback from the inspection. The examination identified the effectiveness of an installation and provides information on how well the methodology works in practice. If there is a poor safety culture in place in an organisation then there will be few accidents reported, hence laser accidents are unlikely to be reported at all.

The GAP is that in organisation with a poor safety culture, there is under reporting of adverse incidents as the norm, so the size of the problem is not representative and no action is taken.

3.7.7 Accidents

It has become clear from the incident databases (3)(4) that awareness of the hazards of cutting or heating substances needs to be raised so that controls such as fume extraction are in place before the operation is started. This covers a wide range of industrial applications, medical procedures and experiments involving a range of chemicals. If an open flame or high voltage were to be used to cut, join, or modify substances the user would be more aware of the hazard of the heat source and fumes but this does not happen so frequently with laser systems. Staff do not recognise or relate that a laser may be a machine under PUWER (49), rather they regard them as a research tool or scientific equipment. Alternatively they are specialists who are ignorant of the general safety culture, hence do not see the hazards. Many of the systems in use have engineered controls superimposed in a layer of administrative controls that are susceptible to human error.

The GAP is if the system has only administrative controls, it is more likely that a hazardous event will occur. If the administrative controls can be replaced by engineering controls the system is less likely to suffer a hazardous event, as engineering controls are inherently more reliable.

3.8 Review of safety information available on CDs

3.8.1 Review of Safety information on CD

Several examples of safety applications available on CD are included in the Table 3.11 below. They are reviewed on the basis of: the functions to allow 'search or index' of main terms allow a user to find the specific area of interest; the 'interactivity class', the use of not only text but also colour pictures, sound and video or animation helps explain a concept and the final column identified any 'test' or self-check that may be included. This allows positive feedback that the information learned and questioned is correct or in error and prompt the person to look at the relevant section again.

The range of CDs reviewed covers not only safety but information databases and applications as the safety CD will identify what should be done and then the parts and applications give solutions and components that could be used. A combination of the three is required to move from identifying the safety issue to solving the problem and implementing a solution.

3.8.2 Review of the IEE wiring Regulations CD.

The wiring regulations were until recently only available in hard copy which made searching and interpretation difficult unless you had a working knowledge and electrical background. Now that they have been made available on CD (101) it allows all of the regulations, the seven guidance notes and the three testing supplements to be searched with hypertext links. There are also video clips and examples of installations. The linkage allows a search to cover the breadth of applications and periods of an installation lifecycle. The diagrams and video are placed to assist explanation that has been identified during classroom training courses to cover common areas that need more detailed information. The opportunity has been taken to supplement the hard copies that were usually black and white with colour diagrams and sound with the video clips.

In each of the sections there are hypertext links backwards as well as forwards that allow either trail to be followed to find a regulation for an installation or how the regulation applies to that situation. There is one guidance note that deals with special locations and has several short sections on groups of locations such as swimming pools, operating rooms and caravans that do not fall into the majority situation of fixed locations of work at home. The features of the IEE CD have met requirements that are similar to those of laser safety. There are some aspects that are present in all cases and regulations that require explanation. At the other end, there are special arrangements that have common solutions that can be applied to that small group. The hypertext links allows rapid movement from the top regulation to the detail of one installation at one time during its life. Many of these features have been adopted in the analysis of requirements of a laser safety CD structure that follows in this chapter.

Table 3.10 Review of safety/information elements on safety CD's.

CD title	Subject	Index search	Interactive	Test
Schmersal Industries (102)	Electrical safety systems	Yes	Animations and photos	No
Guard Master (103)	Safety Navigator, interlocking systems	Yes	Animations and video	Yes
Erwin Sick (104)	Opto-electronic protective devices	Yes	Animations	No
BBC staff training (105)	General Health and safety with risk assessments	Yes	Video	Yes
Festo (106)	Pneumatic equipment selector	Yes	Photos	No
Skiffy (107)	Plastic fastening product selector	Yes	Photos	No
IEEE LEOS (108)	Journal collection of IEEE laser society	Yes	No	No
EEF display screens (109)	VDU regulations	Yes	Photos	No
Radio Spare (110)	Electrical and mechanical components	Yes Yes	Photos and animations	No
IEE wiring regulations (111)	Electrical safety and design	Yes Yes	Animations, video photo	No
HSE guide electrical safety (112)	Electrical safety regulations and guidance	Yes Yes	Animations, video photo	No
The state of occupational health and safety in Europe (113)	Reports of the standard of Health and safety	Yes	Links	No

The Schmersal machine tool safety systems, (102) Guard master for safety interlocks (103) and Erwin Sick optical interlocks (104) to safe guard moving parts show three approaches to the same area of electrical interlock/controls of hazardous areas. They

range from just part numbers of hardware to animated examples, with photographic links to real life installations, that show what has been done to meet the safety requirements, that could as easily be applied to a piece of laser equipment.

There are several key areas where there are GAPS between the requirements of the standards and the understanding and application, which has been seen and reported.

3.9 Applying the ideas in the workplace, human factors.

3.9.1 Introduction.

Even if the safety information is sufficient, easily accessible, and is combined with training that identified the hazards and areas to be developed it may still not be applied.(114) Internet searches are superior and can provide the information required to take a person a long way towards working in a safe way, in a safe environment. However there is another key element to achieve a good level of safety and that is the culture of the organisation and the culture of people working in it. The "human factor" is a gateway to how much more effective the application of information and training can be when it is embraced and applied in the workplace. (115)

In the past, if there was an incident that had no obvious cause such as a broken part, the blame was usually pointed at the employee, who was said to be careless. This antiquated approach has been reviewed and if the root cause was the person, then the reason for them acting in that manner or making the mistake can often have been prevented. (116)

3.9.2 How human factors can be applied to laser safety

The general safety of establishments will influence the laser safety aspects, as the culture of the workplace is a dominant feature in human factors. The base line safety features and procedures for general safety set the agenda for the laser safety systems. If there are generally engineered controls and procedures to work to, then there is a standard set for the workplace. The culture of compliance or to ignore the standards can then be assessed. Several research reports by the HSE (117)(118)(119)(120) confirm

manning levels, training, skill level and emergency planning all affect the culture and hence safety of the workplace.

If there are few engineering controls or no procedures for how to work, custom and practice is the dominant system. (121) Staff will either be trained or copy the others in the work place, to do the task with the minimum effort, at an acceptable risk. The adage of 'familiarity breeds contempt' is aptly defined, as periods without incidents then question why all of the safeguards are required, as no incident has occurred. This does not take account of near misses or how serious an incident may be. (122) If the situation is viewed in isolation, the laser can have engineered control fitted when manufactured and procedures that safeguard the laser but may not cover the associated equipment, such as exhaust ventilation. The approach must be to assess the workplace, task and people involved. The normal process can be reviewed but the one off jobs, service or maintenance should not be overlooked, as these are times of high risk as they are outside the normal operating envelope.

The approach to service is often to have contract or manufacturer service staff undertake the work. This then uses people who do the tasks on a regular basis and are therefore more familiar with the task. The environment changes for them and the interface between the company and the contract staff is a point that needs to be established and all need to be clear about who does what and what their responsibilities are throughout the work. (123) Hand over between shifts and between different groups of people is a point where information can be missed or misinterpreted, which then can lead to an incident. (124)(125) Clear responsibilities and hand over can be formal but often the boundaries are not defined and the risk of incidents is increased. The manufacturers should train their staff and provide written procedures for maintenance and repair that defines who and what. However this is often not provided or is of poor quality. (66).

Given that there is good safety in general or that general safety is assessed as part of the process, the specifics of laser safety can be assessed. The process of workplace, culture and task are the same topics as for the general safety assessment. The specific issues relating to laser use, their power and configuration should then be reviewed.

3.9.3 How human factors can be improved

The original HSE 48 human factors publication in 1989 (99) was up dated in 1999 (126). The range of companies was widened to address all areas of work not just industry. The update included more recent incidents and changes in language but also took into account the increased awareness of H&S, as well as providing support for 'getting started' of how to apply the system in the individuals workplace.

The company documents from the USA DOE (78) and UK AWE (116) are both written to address the higher hazard issue of the nuclear industries. The principles are similar to the HSE but the detail of reviews of indicators and process controls are far more extensive to address these key interfaces that have been identified as points where information breakdown and hence incidents can occur.

The three essential aspects of human factors, personal, job and organisation are then addressed in a HSE research report. (126) The personal aspects include their perceptual, intellectual, mental and physical attributes, as well as their capability for performing both routine and non-routine tasks and attitude to safety. The aspects of the task cover the ergonomics, sequence and equipment involved with the work. The third item is the organisational characteristic effect on safety-related performance, which is really the safety culture of the organisation. These include the impact of co-workers (peer pressure) as well as that of supervisors and management. Incident reports support the above issues and their effect on the workers.

The technological safety issues of lasers often obscure the emotional factors, attitudes, and people's individual response to their working environment, which are then commonly ignored. It then follows that the ability to understand and apply the information that has been given, to recognise potential hazards, faulty perceptions of the risks involved, leads to inappropriate attitudes to safety. These issues combined with work pressures, accepted practices, poor management examples may not be supportive of safe working. (115)(121)

The challenge of laser safety training is to recognise and deal with these human factor issues. Training programmes need to be restructured to address attitudinal and behavioural aspects of workplace safety in addition to the basic knowledge requirements. In applying these principles to practical training experience, the human factors study programme (99) has demonstrated that there are three major areas in laser safety that should be addressed as part of any training that is given, whatever mode of teaching is employed. A vital part of laser safety training is assisting people in the implementation of what has been learnt. Training people with the necessary knowledge but without also giving them guidance on how to apply it can be ineffective. (127)(1)

This process of group involvement helped to ensure that employees had 'ownership' of, and hence a greater commitment to, the safety schemes. The feedback programme has already demonstrated significant safety improvements and is to be extended. This learning has been adopted in the UK and is further supported by the approach of the HSE to large firms driving up standards with subcontracting companies that supply them with goods and services.(29)

3.9.4 Human factors, Department of Environment DOE Safety documents.

The documents (128)(99) on human factors cover in depth analysis of the circumstance that may allow incorrect or mistaken actions during work in relation to high hazard process. The studies (99) cover general arrangements and then specific areas such as people's values and emotional state, if the task is repetitive and the likelihood of a mistaken action or error which have ranges of values assigned that are then used in fault tree or reliability assessment of typical tasks. This then allows control measures such as inspections, breaks or changes of work to be put in place that would lower the chance of an event occurring. This approach is supported by other techniques that provide support in depth such that if a system fails there is a back up or further control that would minimise the consequences.

3.9.5 Human factors in safety documents of a large UK defence company.

The document (116) has been developed to support safety assessments and safety cases that range from industrial to nuclear scenarios. The methodologies have been structured on industry standards with check sheets, flow charts and probability criteria. The approach is modular in that the task, the person or the workplace can be examined individually or as combinations. The techniques (Hazop, Hazan, risk assessment, inspection) (129) for analysis of hazards and risks, have been developed for very high hazard or high consequence tasks, workplaces and people. The process can be applied to less hazardous workplaces and to experimental tasks.

3.9.6 How human factors can be applied to lasers safety.

The techniques discussed above cover high hazard work places but the techniques can still be used in less hazardous areas. The HSE document (117) deals with an industrial range of applications but the same approach can be used for research and experimental workplaces. The hierarchy of controls that can be applied to equipment and task may identify that a key control measure is to separate staff and equipment with an enclosed laser which will minimise the risk of exposure to a beam. If the work involves regular adjustment, remote drives or motorised controls can be effective by not requiring the staff to be near the beam and giving them easier control. If the task is taken as normal industrial work then the laser aspects considered there are additional control measures that have been applied and proved in other workplaces that can be modified to improve access, reduce fatigue and reduce the hazards of injury/damage to equipment.

3.10 Summary

Safety solutions are often not applied in the workplace. Understanding the motivation and why a person takes risks and does not follow procedures but wants to do a good job with the least effort can be explained by human factor analysis. Work tasks often develop over time or are not planned so that there is no design of the task and the individual is left to decide how to do the work and in what sequence.

Involving the person doing the task is often important, not only to understand why they want to do it in a particular sequence or use a particular technique but also understand the culture of the individuals and the workplace. Understanding and having a positive influence on these drivers and culture may have a stronger influence than any equipment or procedures on the safety of the work. Improving by retraining and analysing work task gives the opportunity for discussion and to develop safer procedures. (129) If the staff do not work safely, to good practice or the engineering controls are not applied or are by passed, all of the good ideas and learning is lost, which may make the staff more likely to have an accident.

3.10.1 Standards are not updated or applied and lack easily accessible practical examples.

There are international laser standards but they are not applied. The general safety hazards should be addressed as well as laser light. There is a lack of practical examples that could be adapted to meet the minimum requirements. The laser standards should keep pace with the development of faster pulses and technology changes. The industrial standards do develop to meet changes in work practices and technical developments. These should lead to the risk assessment of lasers under MHSWR and PUWER regulations in industry.

3.10.2 Improve the structure and content of the standards.

Information in the laser standards/literature is good but hard to find. Make it easier to access and links between subjects and applications for laser and non-laser light hazards. Embrace all of the hazards under PUWER and adopt an electronic medium of solutions.

3.10.3 Accredited European training course format for LSO, operator and users.

Develop and approve an accredited European, National training scheme for LSOs, operators and users. Define the competency and inspection of operators of laser equipment and displays.

3.10.4 Good laser safety is difficult to achieve within a poor safety culture.

LSOs, users and safety staff should have the competency in safety to look for hazards, both industrial safety and laser light. Lasers are used in a wide range of applications. They should be approached from a position of knowledge rather than ignorance. If the workplace has a poor safety culture then it is difficult to have good safety in any one area as the support and finances are unlikely to be available.

3.10.5 Review and learning from near misses will help prevent accidents.

Lessons learned from incidents and near miss information should be fed back to improve systems and controls. If the information is linked to a national or worldwide site, the standards can be amended regularly to assist a greater number of people.

3.10.6 Suitable use/service/maintenance information must be provided by manufacturers.

Service, maintenance and user information are often poor. The additional hazards of service and maintenance information and training seldom addresses the increased risk of those periods when covers are removed and the normal operational controls are not applied. Replacing parts and then re-commissioning requires control of the unusual task or carries the additional risk that equipment has not been proved or approved in the new arrangement.

4.0 Research & surveys.

4.1 Research

4.1.1 Introduction

Several of the large scientific organisations in the UK (for example MoD, RAL, AEA), have a large number of lasers in use and hence have training and safety systems to address the hazards of lasers. Discussion with LSOs (130) regarding training and the support provided within these organisations has highlighted a shortfall in training and experience relating to specific applications. Although lasers are used in many diverse applications, support should be available from the standards to give the user the key points for safeguards and controls.

Following discussion with the LSOs that have attended the training course organised by the NRPB and Loughborough University, it was apparent that there was a shortfall in the support at their place of work, for the controls and standards that the LSOs wanted to install at the point of use and what they were allowed to provide.
(131)(132)(133)(134)

In parallel LSOs in the National Laboratories and the San Francisco Bay area, USA have identified similar shortfalls in sharing information and common training items. Table 4.1 overleaf highlights the short falls in each area, with the most difficult to achieve first. The number in the end column shows the perception of the greatest benefit by the LSOs.

The analysis of the issues ranked similarly across topics, as well as in different parts of the world. The relationship is such that the assessment of these data using statistical methods does not change the underlying issue that the benefit in sharing lessons learned and putting preventive measures in place is not happening. Further down the list, the issues are linked more closely to personal or site specific issues that are not identified at all locations.

The data has been drawn from several databases over several years and presents a consistent result. The left hand column of Table 4.1 ranks the anticipated difficulty of achieving the desired changes, number 1 being the most difficult, by the USA LSOs. This reflects their experience of previously tried but failed solutions or that there is not a successful model to follow which has set the preconceptions of those surveyed.

Table 4.1 Ranking of anticipated difficult to achieve improvements in training.(135)

Item of training in order of most difficult to achieve.	Highest number is perceived as the most beneficial
1. Standard Training Materials Outline	5
2. Share Lessons Learned	6
3. External Review of Corrective Action Plans	3
4. Degree of Commitment to ANSI Z136.1	1
5. Eyewear Testing for Nano-second Pulse	3
6. Standard Policy	2
7. Purpose and Reciprocity of Eye Examinations	2
8. Web-Based Training for Visiting Scientists	3
9. Reciprocity of Training	6
10. LSO Certification	4
11. Share Expertise	5
12. Points-of-Contact List	5
13. ANSI Std Revision [Reciprocity of Training]	1
14. Laser Propagation Airspace Safety	1
15. Class 3a Laser Pointer Policy	2
16. Level of Control/Authority of LSO	2
17. Inventory List of equipment	1

The concern discussed was regarding the ignorance before attending the course. Attendees were knowledgeable in their field but had either not been trained or had time to search for the information to make the installations safe and comply with safety standards. The training course could change the person's perception and intended behaviour but this does not always achieve the desired improvements in the workplace, (136)(5) due to business and peer pressure.

4.1.1.1 Users' perception of specific laser safety requirements.

Raymond et al 1995 (137) gauged the changes of attitude that could be achieved during a course on laser safety. The approach of the courses is to cover the radiation aspects of laser safety and then some of the associated hazards. The wider safety implications of common hazards in a workplace occur more often than the laser hazard of radiation. Often the attendees quoted that eye wear was essential, whereas engineering controls were important, which is in contrast to the accepted H&S hierarchy of fixed, interlocked, automatic and trip engineering controls before procedural controls and PPE as the last option. The approach took the premise that if staff did not slip, trip or fall and did not have shocks, then there would be less likelihood that they would have a laser safety accident as the culture towards the general safety requirements drove improvements in the laser safety area as well.

They (137) concluded that amendment to the content of the training course and more information from manufacturers would support a better safety culture in the workplace, which would allow improvements in the standards and types of safety systems applied, which in turn would reduce the number of laser incidents. Specific examples of applied engineering controls with a general safety system will meet the requirements of the standards.

These findings acknowledge that the manufacturers do provide information, but when a laser is bought as a component of an experiment, the manufacturer can offer advice but the user may not have devised the final configuration or be allowed to explain the arrangements for commercial reasons.

4.1.1.2 Support required to put specific laser safety requirements in place.

After initial discussions with LSOs at NRPB and Loughborough University, further conversations with other LSOs identified that the shortfall between their present installations and that required by the standard were not isolated cases but the general case. (130)

As with much of health and safety legislation, the support and ideas that improve equipment are for the highest hazard and most frequent incident items have the highest profile. There appeared to be common themes of GAPS and shortfalls due to constraints of finance, time or pressure of production. As with most issues that have limited resources, the best approach is to provide useful solutions to key people that can be implemented at reasonable costs.

Research in this study was centred on answering the following questions:-

Comprehension of where laser safety fits into machinery safety.

What information was available?

What lessons for improvements had been identified, if not learned?

What format would suit most people to assist them to implement the changes and broaden their views to identify other hazards such as electric shock, toxic gases or pressure systems, which must also be taken into account when assessing the risks?

4.1.2 Areas of investigation.

It was necessary to look at the range of people involved with lasers and how they interacted with the function of the lasers. The literature search (chapter 3) provides a good idea of the range of laser applications, locations, and industries in which lasers are used.

To get first hand information of laser installations and use, installations were visited to see the application and how the staff interfaced with the laser to gather information that has been collated in the surveys (chapter 4). The similarities of systems, different power

levels, access controls, precision and strength, allowed the definition of common use groups and types of laser applications. This allowed comparisons to be made between the groups, the standards and how accessible the requirements are to the designer, user, operator and LSO.

4.1.2.1 Groups to examine, common factors.

By comparing the hazards associated with lasers (4) and information for LSOs (135)(67)(130), several groups of users, types of laser, applications and sets of legislation (47) were identified that could provide a useful grouping of common factors relating to lasers. As the laser has such a wide variety of uses, the broad applications were grouped and tested against the scope to confirm the suitability of the grouping.

The reason to take this approach was that it would allow the wide range of applications to be more effectively addressed within a framework that would give a common application, and then provide several subdivisions of the main application. The common hazards and constraints would then be able to be addressed in a systematic approach.

The groups chosen are to cross-reference the operation/technique and area the work is being performed in to produce the Table 4.2 below. The power, class and types of laser were examined but did not cover the controls and user groups to the same extent.

Table 4.2 Range of operations applied in sectors/workplaces.

	Industrial	Medical	Research	Entertainment
Cut	✓	✓	✓	
Join	✓	✓	✓	
Measure	✓	✓	✓	
Illuminate	✓		✓	✓

The operations of cut, join, measure and illuminate cover the tasks that a laser could be used for and hence would indicate some task related controls that would be appropriate.

If there is enough power to cut or join material there is a requirement to enclose or interlock the beam. If the laser is used for measuring or illuminating, it is probably being used in a wider area that is likely to be unsuitable to enclose, such as range finding for a guidance system. This would present a problem over long distances (NOHD issue).

The sector/workplace are linked by the area of use and hence the operations that the staff perform. Industrial processes often lend themselves to fixed guards, whereas in research there is often a temporary system that is changed frequently and hence requires a modular approach of guards and interlocks that can be changed to suit the new configuration.

4.1.2.2 Methods of investigation of groups

The decision to review the operations listed in Table 4.2 allowed a comparison to be made with some previous industrial studies regarding laser safety of 5 and 10 years ago. This would give a comparison in time and allow links between legislation, information and culture to be explored.

A survey of a representative sample of each sector/workplace was taken to gauge the present response to legislation with regard to the support within the organisation and prevailing general safety culture. The figures do not show any improvement over the 1990s. There has been a step improvement in some aspects of safety on construction sites and with equipment for manual handling systems. These have been driven by changes in legislation such as the Construction (Design and Management) Regulations (CDM) (138), The Management of Health and Safety at Work Regulations (47) and the Manual Handling Operations Regulations (139) that have been supported by inspection and enforcement to encourage companies to comply. There are still many fatalities each year in construction and the number of days lost to back injury is still high. The heightened awareness has improved safety but has also increased the reporting of incidents, so that any improvements in prevention are hidden by more events being reported.

A survey of laser suppliers was undertaken to gather data regarding the present regard and approach to safety within the improvements and changes of culture driven by other safety issues.

4.1.3 Comparison with other areas, organisations and industries.

4.1.3.1 Size of companies.

A small metal cutting company that uses lasers may not have expertise within the company to apply all of the safety requirements and compete with other technologies or methods of material processing. Safety, training and guidance are overheads that the customers may not want to pay for, so do not get supported. During the survey, the effect of the size of the company was assessed against the safety systems and procedures they employ and apply in practice. The money and time that can be given to training and updates is likely to be more limited in smaller companies than larger concerns. This reduces the opportunity to have the planning and information to encourage changes to improve safety.

Support for the operator or maintainer by the application of newer information technologies was examined in the practical arrangements of items such as measuring the power sent and arriving at the work point, and also the software developments that make information access and presentation more useful. This can range from maintenance manuals that have time based maintenance and service items listed to fault trees or interactive fault diagnosis. There are cases where faults are identified by the equipment that, rather than producing an error code, gives the fault information in text with suggested corrective actions. It must be recognised that these levels are only available for larger, more common machines that have an economy of scale to provide that level of support. It will filter through to smaller equipment in time, as costs reduce and flexibility increases.

To support the knowledge GAP, computer aided learning (CAL) has developed with the advent of CD ROMs and the internet that allow easy and sometimes free access to training material and test questions of many areas of laser safety. (72)(74) There are

stand alone packages that deal with topics by discipline, but these will generally be theoretical rather than practical examples. (142). The ability to teach and then test on a topic, allowing the person to go at their own speed is a key advantage, otherwise people lose concentration and interest if the information is too fast or slow. (78)(136)

Access and how the information is targeted were reviewed. Packages may be limited or not updated. As lasers are used in such a wide variety of applications and the skill and knowledge varies with the individual using or maintaining the equipment there has to be a spread of information and level of detail to match a variety of needs.(140)

There is also a concern that with Internet training there is no proof of the person actually having done the training or understanding what they have covered. Indeed some institutions have tried CAL and are returning to classroom based training due to associated issues of liability claims.(135) The key is to provide information in the areas the person is focusing on and support that information with back up materials or associated subjects that cover the use, operation, installation and service/maintenance of the equipment.

As with non laser equipment, the hazards, operation and controls must consider all of the hazards not just the laser light hazards as the person may not be aware of associated hazards any more than the light hazards.(67)(46)

4.1.4 Summary.

A survey of the present state of safety training and perception of the need for LSOs within laser manufacturers gauged the developments since the last two studies in similar areas. There is a GAP in the perception of what is safe and poor supply of information to identify the shortfalls. The survey confirmed that specialists do not go outside their area of expertise in laser safety to general safety. Training and a set minimum level of qualifications will support the application of the laser safety standards.

Changes to the general safety culture through the steps the HSE have taken and changes in public perception drive many initiatives and developments. The changes to H&S

legislation have had an effect on general safety so the effect within the laser areas has been examined. This should also focus on the harmonisation of the laser regulations/standards, with amendments of 2001, Z136 and IEC/BS EN 60825 as they take account of more recent physiological data and provide better guidance on how to apply the standards. Changes to the regulations follow standards because of the time of due process to enact into law.

A computer based software package can provide information, but it is fixed in time. A suggestion of the scope and content of a laser safety CD has been developed although the production and distribution would require funding and international support to address a suitably sized audience and wide range of topics. As a consequence of these arguments an information based CD had been developed as part of this thesis. However when trialled it showed limitations of lack of specific topic information and that it is fixed in time. A more suitable approach is to make the present information accessible and deliver the knowledge and wisdom to the user. The access if via the Internet can be up to date each time it is accessed and can be searched for specific topics.

4.2 Surveys of implementation of safety systems & control.

4.2.1 Introduction.

As lasers are used in numerous places and on diverse applications, (Table 4.2) the intention of the survey in this study was to explore a representative number of respondents in each of the areas. The purpose of the survey is to examine the implementation of the safety systems and controls in those situations and to compare the findings with the 1990 (92) and 1994 (23) surveys.

There are 6 LSOs within the host company that operate in widely different areas of application (measurement, communications, illumination, metal cutting and joining) who allowed trials of the survey questions before dissemination to the wider LSO community. Contact has been made with people that attended the LSO forum at Loughborough University Open Forum in 1997, 1998 and 1999, which has allowed the

selection of people and areas of application that are different from those at the host organisation. A few respondents overlap and that has given confidence to the data collected from outside the company. Details of the organisations and the position the people contacted hold are listed in chapter 9.2, however some provided information in confidence and hence are not listed.

The intention was to ask a series of questions that would explore the topics and boundaries of each company's safety system, culture and understanding of H&S requirements, then explore how they apply those requirements within their organisation. One intention is to take into account the culture of the company; this may only rank as fair in terms of laser safety but be operating within a low general safety culture. This would reflect well against a company with a good general safety culture but which has little regard for laser controls.

The format of the survey has also allowed comparison to be made with two previous surveys of industrial safety in relation to the use of laser systems.

4.2.2 Scope and size of surveys.

4.2.2.1 Previous surveys.

Two surveys (23) and (92) of laser manufacturers reviewed in the literature provide one of the baselines for the present survey. The previous survey findings over the late 1980s and early 1990s were that many manufacturers were seeing adverse incidents but few would support steps to take action to improve the situation.

The second survey in 1994 found similar problems to the first and could find no evidence of improvements in the intervening 5 years. A knowledge based system for laser safety assessment was proposed that would gather the details of a diverse range of technical areas and other issues such as the human interface to provide support of a systematic approach to address the hazards. A further 5 years later and the position has remained the same.

Of more concern is that all of the groups interviewed repeatedly highlighted the issue of difficulty interpreting the laser safety standards. The Eureka 643 Handbook on industrial laser safety has most of the features that were defined by the survey. Nevertheless, it was not readily available (2002) to provide advice that is more appropriate and guidance.

These later surveys confirm the findings of the earlier surveys, in that the standards are still difficult to understand and most laser applications have some specialist parts of the laser process or application that require in depth knowledge. The following surveys were conducted to investigate how well the present standards are understood and applied. Since even if the standards are read and understood they are not always complied with, is it that the safeguards are still not understood or that they are not engineered into the systems during assembly and commissioning?

4.2.2.2 Present surveys 2000-2001.

These surveys have been aimed at several user groups, wider than the 1990s surveys.

- Manufacturing industry.
- Research, military.
- Medical, National Health Service.
- Entertainment.

The surveys were intended to test the user groups' understanding of the standards, the level of support they provide to check the safeguards and associated hazards are controlled. The training given and company organisation was also examined, as laser safety can not exist in an organisation without other general safety culture to support the systems. The previous studies did not establish if there was an existing safety culture within the work place or how many lasers and variations of types. The questions relating to laser standards and their applications are similar, but the medical and PPE areas were not covered. The structure and topics were chosen to establish the size of enterprise, the general safety culture and specific laser safety culture in line with accepted social research methods. (141)

4.2.3 Structure of survey form.

The survey form was developed to match the topics covered in the standards and to establish the resources that a company applied to operate an effective safety system. Several companies, organisations or events were studied and the results compared to establish if they were typical of their group or if additional instances were required.

The survey was scored/marked to explore the level of compliance against a good safety standard. The good safety standard is taken as being above the legal minimum and recognised within their sector as a good performer in safety. If the company had procedures or systems in place and they were of a good standard then they were marked acceptable. This will show that some areas are acceptable 100%, ranging through to other areas failing to meet the requirements getting 0%. The figures for each sector will be then averaged to give a representative response across the sector/workplaces.

The Table below shows the general topics covered in the surveys

Table 4.3 Grouping of questions from surveys.

	Topic group	Specific area	Complies
1	General safety & procedures	Have you got a safety policy/safety officer Are there company safety procedures/instructions	✓
2	Types of lasers	What class and number of lasers in use	Few some many
3	LSO	If you need one have you got one appointed	✓
4	Training	Training and education, refresh, updates of staff	✓
5	Standards	Do you know the standards?	✓
6	Controls	Control in place	✓
7	Medical	Is there medical surveillance and support?	✓
8	Eyewear	PPE required? Competent calculation of OD?	✓
9	Associated risks	Fumes, shock, burn, poison, public	✓

The question sheet (example and typical response follow) expands the topic areas of Table 4.3 to establish more detail, such as the general size of the company, the safety arrangements and staff, and if they knew and applied the requirements of safety legislation. The next section established the size of the company and its area of application, the number of lasers and classes in use. A large company can carry more support than one with only a few people, who will be focused on work tasks. The training questions were asked to identify if the organisation was training staff and then refreshing the training after a period of time.

The next series of questions allowed discussion relating to the experience and training of the LSO and others with safety responsibilities. The question that asked which standards, IEC/BS EN 60825 or Z136.1 were used, was related to importing lasers and how well it was understood, that if they were manufactured to a different standard or class, how that would effect the required controls and maintenance procedures, CE marking and approval processes.

The medical surveillance question was to gain an additional measure of the general safety standards and what specific preventative or emergency arrangements there were in place at that company. The last part regarding eyewear was to cover, if they used PPE, was it correct and who would support the laser beam power safety calculations. The requirement to cover visitors and non-employees can sometimes be missed. There are usually some contractors or other non-employees that go into a company and there should be provision to escort and safeguard their health and safety.

4.2.3.1 Indicators in the survey sheets.

A number in the following survey sheets indicate the number of those people or items of equipment.

✂ In the survey sheets represents No or none.

✓ In the survey sheets represents Yes or acceptable.

show an example and typical response from the survey.

As the laser manufacturers are involved with lasers and their development, they should be more aware of the standards and requirements so were asked more specific questions about training and standards. Are the standards understood and are they applied within the company and how good are their support and organisational arrangements?

4.2.3.2 Survey sheet example of information collected

Table 4.4 Questionnaire for laser users and LSO in other organisations.

Who	Company	When
LSO	University.	During 2000.

Topic group	Specific area	Complies
General safety	Have you got a safety policy	✓
Safety procedures	Are there company safety procedures instructions	✓
	How well does the safety organisation operate	Good
	Safety reps, Union	✓
	Accidents, RIDDOR	✓
	What incidents have there been (No: per year).	2
	Have you got a safety officer	✓
Types of lasers	What class and number of lasers in use	1-4 40
	CW or pulse	✓ ✓
	Visible or invisible	✓ ✓
	Production or experimentation	✓ ✓
LSO	Have you got one appointed	✓
	Full time or part time	Full
	Laser knowledge & how many years experience	15 years
Training	Training and education of staff	✓
	Refresher and updates	✓
	Awareness for other staff	✓
Controls	Are the requirements of 60825 or Z136.1 known	✓
	Are the standards applied and tested	✓
	Planning for modifications, inspections	✓
	HAZOP, change control ,design in house	Change/ design
	Engineering controls in place	✓
	Procedural controls in place	Most
Medical	Is there medical surveillance	✗
	Are employees checked (eye sight)	✓
	Support in case of accidents or NHS	✓
Eyewear	Is it required	✓
	Who calculates the OD	LSO
	How many frequencies are there to cover	Four
	Do you use goggles or spectacle type	Goggles
Associated risks	Fumes, shock, burn, poison, public	✓
Adequately addressed	Visitors	✗

4.2.3.3 Summary of results from sample sheets

Table 4.4 above shows the typical response from a company with a LSO. The survey was conducted across several organisations, in different sectors to confirm a typical profile and if any unusual results occurred, why they were different. Some organisations are more open than others. Some information was supplied in confidence, as public knowledge of the arrangements and incidents could damage the company reputation. Given the number of questions and the acceptable variation between different companies, size and complexity, it made generalisations more difficult than would have been if all the companies were of similar size. However common themes and levels of training, application and compliance became clear as the number of companies surveyed increased.

There were some responses that were not as expected and this was due to the company being an unusual size for that market, or that they were influenced by a large parent company that imposed high standards on the small subsidiary.

The choice of representative groups, their location, size and how many were sampled was based on knowledge of peers in safety posts reflecting on the general safety standards in those sectors and companies. This follows the link that laser safety will be more effective in a company with good general safety standards. The view of large national and multinational companies has been supported by the results and inspections relating to the structure allocated to safety issues. The deviation from the general level expected has had an alternative driver such as the product is dangerous, radioactive or highly flammable. This has improved in some cases and others are lagging behind the legal requirements.

The results of the surveys and attitudes for those visited are discussed in this chapter.

4.2.3.4 Response to questionnaire for laser manufacturer.

Table 4.5 Questionnaire for laser manufacturer.

Who	Company	When
Safety advisor	Laser manufacturer	During 2000
1. Can I talk to your safety officer?		Yes.
2. Do you have or do use lasers?		Yes.
3. What specific controls or procedures do you have?		Some interlocks.
4. What training does your staff have for laser safety?		General H&S training.
5. Do you understand the requirements of 60825?		No.
Topic group	Specific area	Complies
General safety	Have you got a safety policy	✓
Safety procedures	Are there company safety procedures instructions	
	How well does the safety organisation operate	
	Safety reps, Union	✓
	Accidents, RIDDOR	1
	What incidents have there been (No: per year)..	6
	Have you got a laser safety officer	✕
Types of lasers made	What class and number of lasers are made	
	CW or pulse	✓ ✓
	Visible or invisible	✓ ✓
	Production or experimentation	
Training provided	Training and education of purchaser's staff	
	Refresher and updates of purchaser's staff	
	Awareness for other staff	
Standards	Are the requirements of 60825 or Z136.1 known	✕
	Are the standards applied and tested	
	Engineering controls in place	
	Procedural controls in place	✓
Medical	Is there medical surveillance	✕
	Are employees checked (eye sight)	
	Support in case of accidents or NHS	
Eyewear	Is it required	✓
	Who calculates the OD	
	How many frequencies are there to cover	Many
	Do you use goggles or spectacle type	Goggles
Associated risks	Fumes, shock, burn, poison, public	
Adequately addressed	Visitors	
NB not all questions were answered due to commercial confidentiality.		

4.2.4 Response from surveys.

4.2.4.1 Initial survey of Universities and large government organisations.

The initial survey was of Universities based LSOs and large government organisations to establish if there are common themes.

Table 4.6 University and military responses 2001 survey questions. (N = 18)

	Topic group	Specific area	Complies
1	General safety & procedures	Have you got a safety policy/safety officer Are there company safety procedures/instructions	100%
2	Types of lasers	What class and number of lasers in use	Over 50 per site
3	LSO	Have you got one appointed	100%
4	Training	Training and education, refresh, updates of staff	83%
5	Standards	Do you know the standards?	100%
6	Controls	Change control in place	83%
7	Medical	Is there medical surveillance and support?	50%
8	Eyewear	PPE required? Competent calculation of OD?	100%
9	Associated risks	Fumes, shock, burn, poison, public	100%

The Universities were well aware of laser hazards but there was a split between them of those that applied practical safety controls and those that stayed with procedural controls. There appears to be limited finance to get the practical controls in place. The large government organisations had their own safety standards that imposed the requirements of the intentional standards and were generally well supported in practical and procedural control measures. The incident figures in large government organisations (69) do not appear to support this at first glance but the reporting culture is higher than in the Universities or public companies.

4.2.4.2 Survey of manufacturing companies.

The survey of manufacturing companies also establishes that there are common themes.

Table 4.7 Manufacturing companies responses 2001 survey questions. (N = 24)

	Topic group	Specific area	Complies
1	General safety & procedures	Have you got a safety policy/safety officer Are there company safety procedures/instructions	100%
2	Types of lasers	What class and number of lasers in use	Over 30 per site
3	LSO	Have you got one appointed	50%
4	Training	Training and education, refresh, updates of staff	50%
5	Standards	Do you know the standards?	50%
6	Controls	Change control in place	67%
7	Medical	Is there medical surveillance and support?	0%
8	Eyewear	PPE required? Competent calculation of OD?	17%
9	Associated risks	Fumes, shock, burn, poison, public	100%

The survey showed that large manufacturing companies have LSOs and are applying the safety controls but other companies with as many or more powerful lasers give only the minimal acknowledgement to the lasers, being more concerned with associated hazards of electricity and manual handling. This indicates that in some cases that lasers are not seen as hazardous or not included in the general safety system to have effective controls or systems put in place.

4.2.4.3 Survey of Laser manufacturing companies.

This survey of laser manufacturing companies also had common themes.

Table 4.8 Laser Manufacturing companies responses 2001 survey questions.(N = 20)

	Topic group	Specific area	Complies
1	General safety & procedures	Have you got a safety policy/safety officer Are there company safety procedures/instructions	100%
2	Types of lasers	What class and number of lasers in use	10 per site
3	LSO	Have you got one appointed	50%
4	Training	Training and education, refresh, updates of staff	83%
5	Standards	Do you know the standards?	10%
6	Controls	Change control in place	0%
7	Medical	Is there medical surveillance and support?	0%
8	Eyewear	PPE required? Competent calculation of OD?	0%
9	Associated risks	Fumes, shock, burn, poison, public	10%

The survey of laser manufacturers and those associated directly with laser use was undertaken as this group were often smaller companies, which had technical and scientific knowledge but were driven by market competition to meet prices. Contacts were by telephone or conversation, though several were technical visits to the company and its facilities.

4.2.4.4 Survey of medical and NHS organisations.

Table 4.9 Medical and NHS organisations responses 2001 survey questions.(N = 10)

	Topic group	Specific area	Complies
1	General safety & procedures	Have you got a safety policy/safety officer Are there company safety procedures/instructions	100%
2	Types of lasers	What class and number of lasers in use	Over 10 per site
3	LSO	Have you got one appointed	100%
4	Training	Training and education, refresh, updates of staff	100%
5	Standards	Do you know the standards?	100%
6	Controls	Change control in place	100%
7	Medical	Is there medical surveillance and support?	100%
8	Eyewear	PPE required? Competent calculation of OD?	100%
9	Associated risks	Fumes, shock, burn, poison, public	100%

There were very good arrangements and training in place at all of the places contacted. The standards driven by the medical training and regulations have given a supportive framework into which the laser safety aspects have been applied.

Most of the equipment is modern and designed to a high clinical standard that meets PUWER and safety requirements with maintenance support to maintain the functionality and performance.

4.2.4.5 Survey of Entertainment organisations.

Table 4.10 Entertainment organisations responses 2001 survey questions. (N = 8)

	Topic group	Specific area	Complies
1	General safety & procedures	Have you got a safety policy/safety officer Are there company safety procedures/instructions	25%
2	Types of lasers	What class and number of lasers in use	Over 2 per site
3	LSO	Have you got one appointed	50%
4	Training	Training and education, refresh, updates of staff	25%
5	Standards	Do you know the standards?	50%
6	Controls	Change control in place	0%
7	Medical	Is there medical surveillance and support?	0%
8	Eyewear	PPE required? Competent calculation of OD?	25%
9	Associated risks	Fumes, shock, burn, poison, public	50%

The nature of the temporary installations or mobile equipment do not lend themselves to engineered solutions as the light show is to be seen directly rather than boxed or viewed remotely.

Some commercial pressure to minimise costs and cover overheads does lead to some systems being below standard.

A few systems were of a good standard and had adequate procedures, training to address the set up, and operation of the equipment. These are increasing as the standards and acceptability of local inspections and Environmental Health Officers have raised the level of what is acceptable and what is not allowed to be operated.

4.2.5 Techniques used and success of method.

The expectations of the results and why they could deviate was discussed with safety and laser staff to estimate the influence that aspects of the survey could have on the results.

The sector/workplace examined included over 10 Universities. These were chosen first as there was an expectation that the standards would be high given the students' inexperience with lasers and the 'duty of care' from the University. The general standard was towards the best in terms of understanding the requirements and having policies in place. The application of the safeguards fell a little short as the research aspect tended to allow less robust solutions to be applied as the installation was for a short period, typically less than a year.

The hazards were usually addressed within a risk assessment. However suitable controls were not often put in place. There have been several eye strikes at universities that show the precautions were not adequate.

A sub set to the group which has been taken outside the general industrial group is the nuclear industry. This is because the nuclear industry has tighter regulation of their actions and usually a better-developed safety culture. These factors, added to the improved resource and support, make them more aligned to the universities but far more effective in ensuring controls are in place.

The second group was industrial and manufacturing companies that either have a good design and installation that is effective and well documented or the laser is an additional item to give a monitoring or sensing function that has been literally bolted on and once it works left alone without further refinement.

The third group mainly consisted of the medical practitioners and National Health Service (NHS) staff in particular. The controls of the NHS and the standards drive the correct engineering controls and cover maintenance areas. The use and applications tend

to be an area that by its very nature is weaker, as the use is controlled by hand and aimed at a person. Complications have occurred due to problems caused by the laser - mainly fires and burns.(4) The laser is a versatile tool and the interaction between medical staff and patient will always have uncertainties, as even if the patient is immobile the medical staff can make errors that can not be controlled by engineering controls or guards.

The last group and maybe the most varied is the entertainment industry. This is taken to cover from formal well run laser displays as part of a classical concert through pop concerts to the uncontrolled scanning using laser pointers by the audience. The main concern is eye strike but there are low incident numbers recorded which is due to other influences on the people present and the less formal reporting route if a person realises they have had an eye strike. The formal events that were supervised by the Environmental Health Officer with LSO support covered half of the topics such as general safety procedures and associated hazards through controls and training but did not have health surveillance or eyewear included. The uncontrolled scanning and public with laser pointers do not appear to have any regard to others safety.

4.2.6 Results of surveys.

The overall number of surveys conducted is nearly 100, each one generally taking more than half a day. This allowed time to assess the systems and arrangements to confirm that the answers reflected the actual arrangements within the organisation. Each survey was conducted in person and most had an inspection of the facilities and a chance to talk to other staff that reinforced the statements and information provided.

The level of operation of the 'safety staff', was in line with general safety operation and support to the organisation. The LSO was usually an additional appointment to a safety post. At the lowest end of support there was little if any training given to operators with maintenance bought in from the manufacturers of the laser.

The table below shows the results of the surveys by group against the training and appointment of a LSO. (All required LSOs)

Table 4.11 Number of staff trained and LSO's in companies.

Group	Total number	Training of staff		LSO appointed	
		Yes	No	Yes	No
Research, military	18	18	0	16	2
Manufacturing industry.	24	7	17	6	18
Laser manufacturing.	20	5	15	4	16
Medical, NHS	10	10	0	10	0
Entertainment	8	6	2	2	6
Total	80	57.5 %	42.5 %	47.5 %	52.5 %

The following five charts show the results from the questionnaires in the separate categories of Entertainment, Laser manufacturers, Manufacturing, University and NHS medical. The higher the score, further to the right, the better the standard of compliance, with the criteria set for this survey. The headings on the left are topics from the questionnaires used during the surveys.

Figure 4.1 Chart of results from University and military questionnaire.

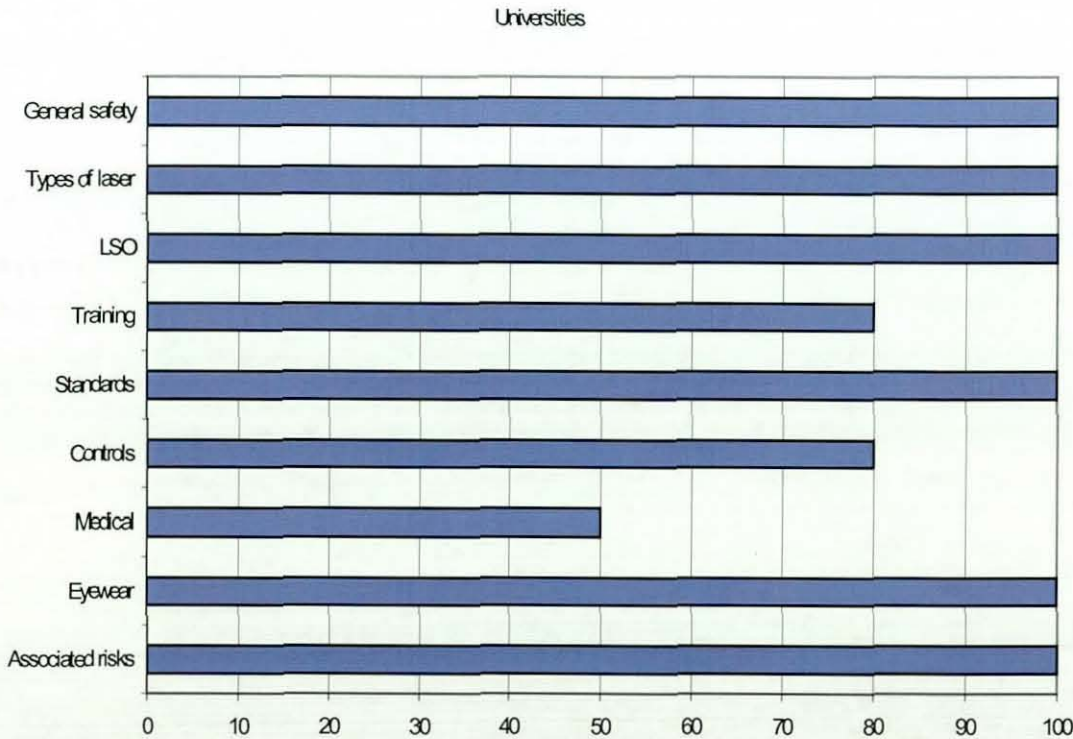


Figure 4.2 Chart of results from Manufacturing questionnaire.

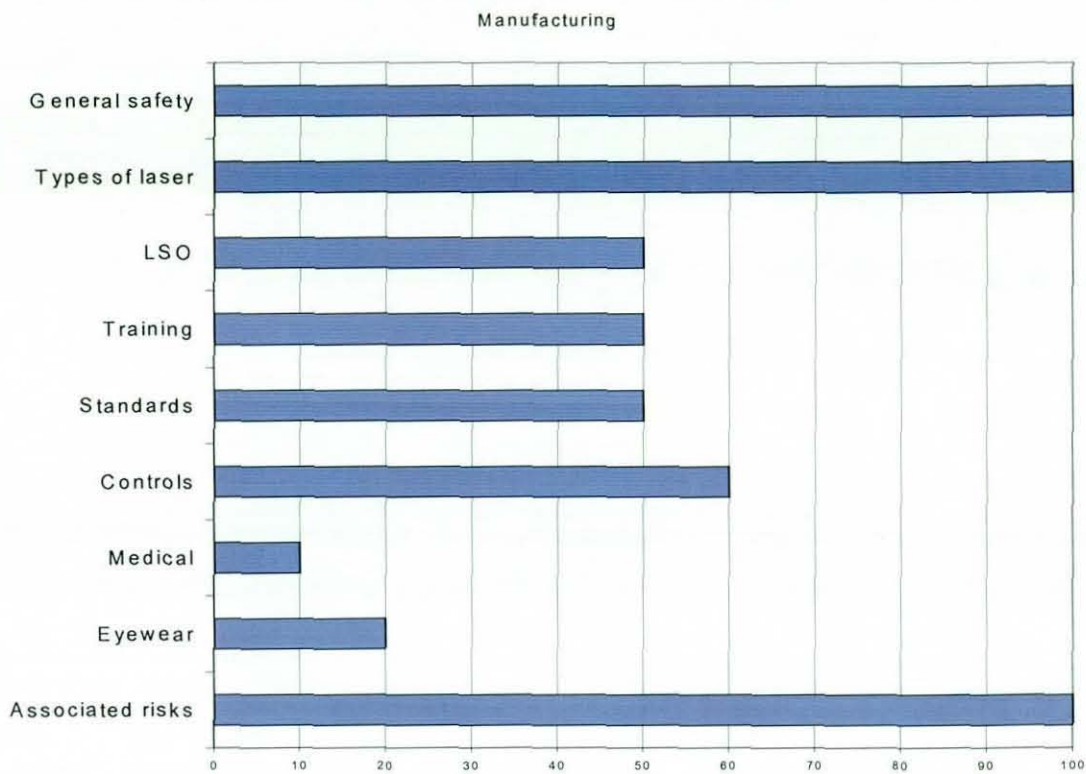


Figure 4.3 Chart of results from Laser Manufacturing questionnaire.

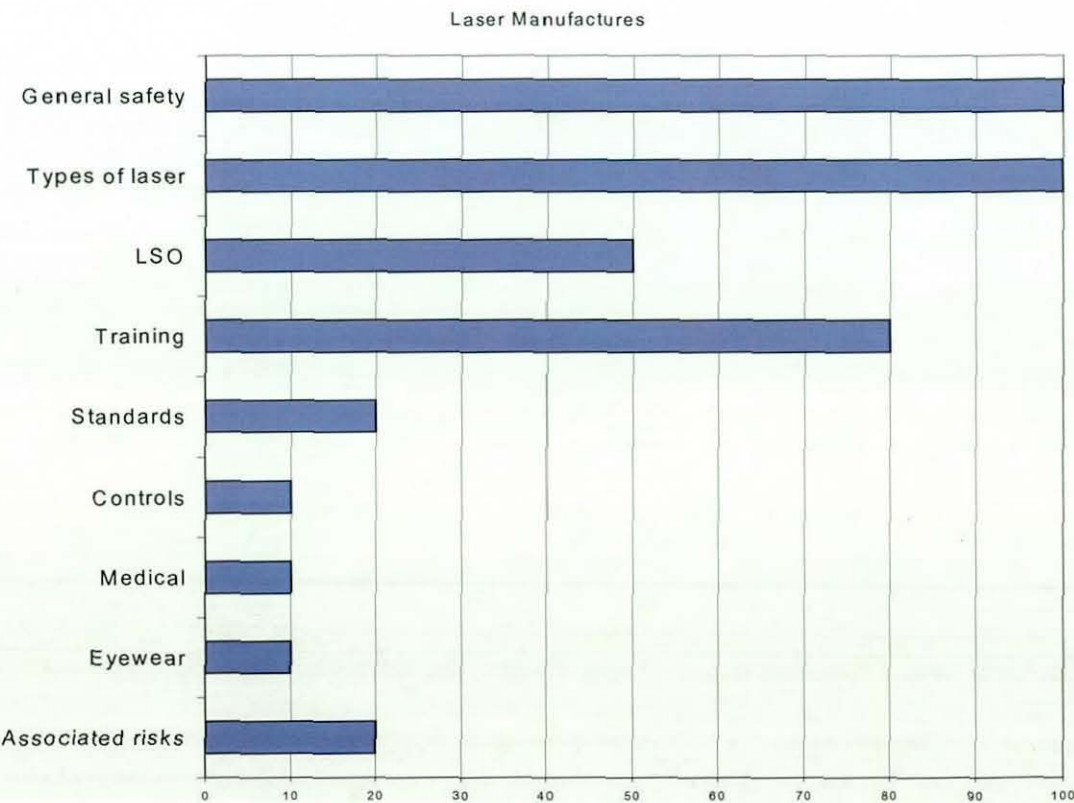


Figure 4.4 Chart of results from NHS questionnaire.

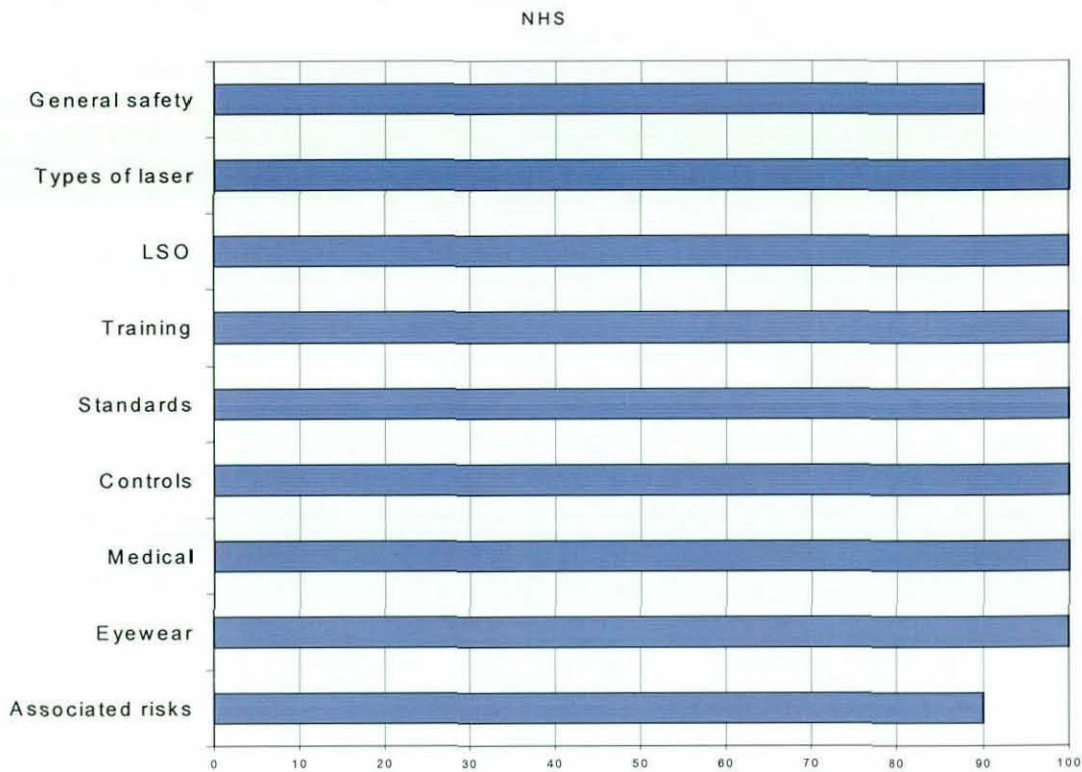
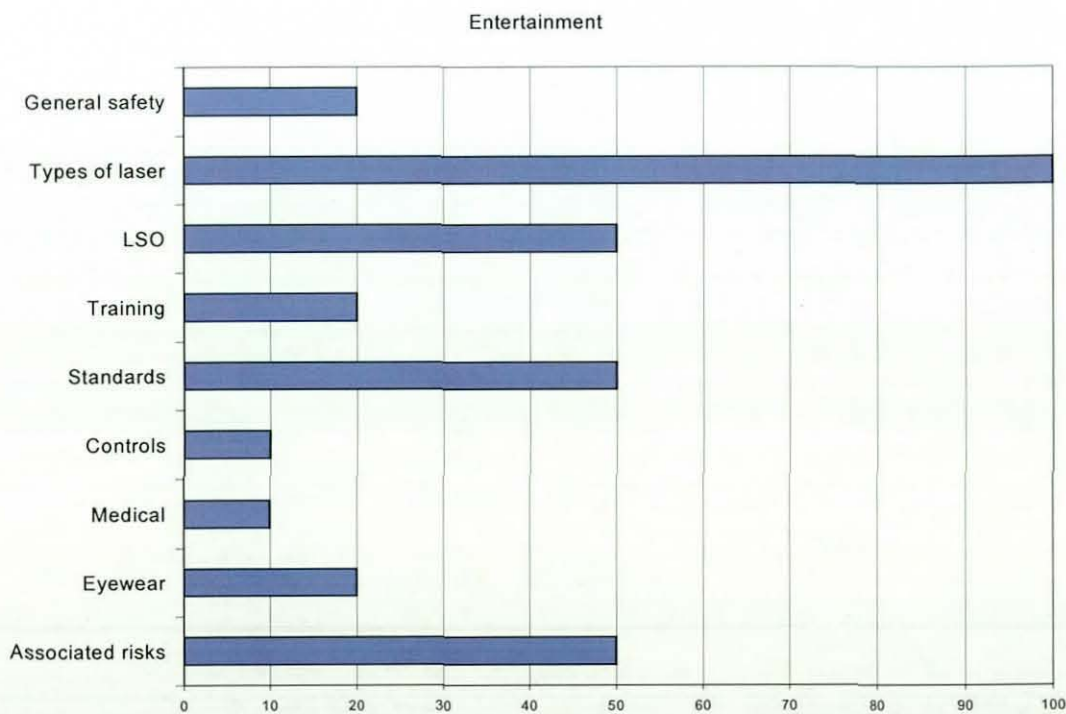
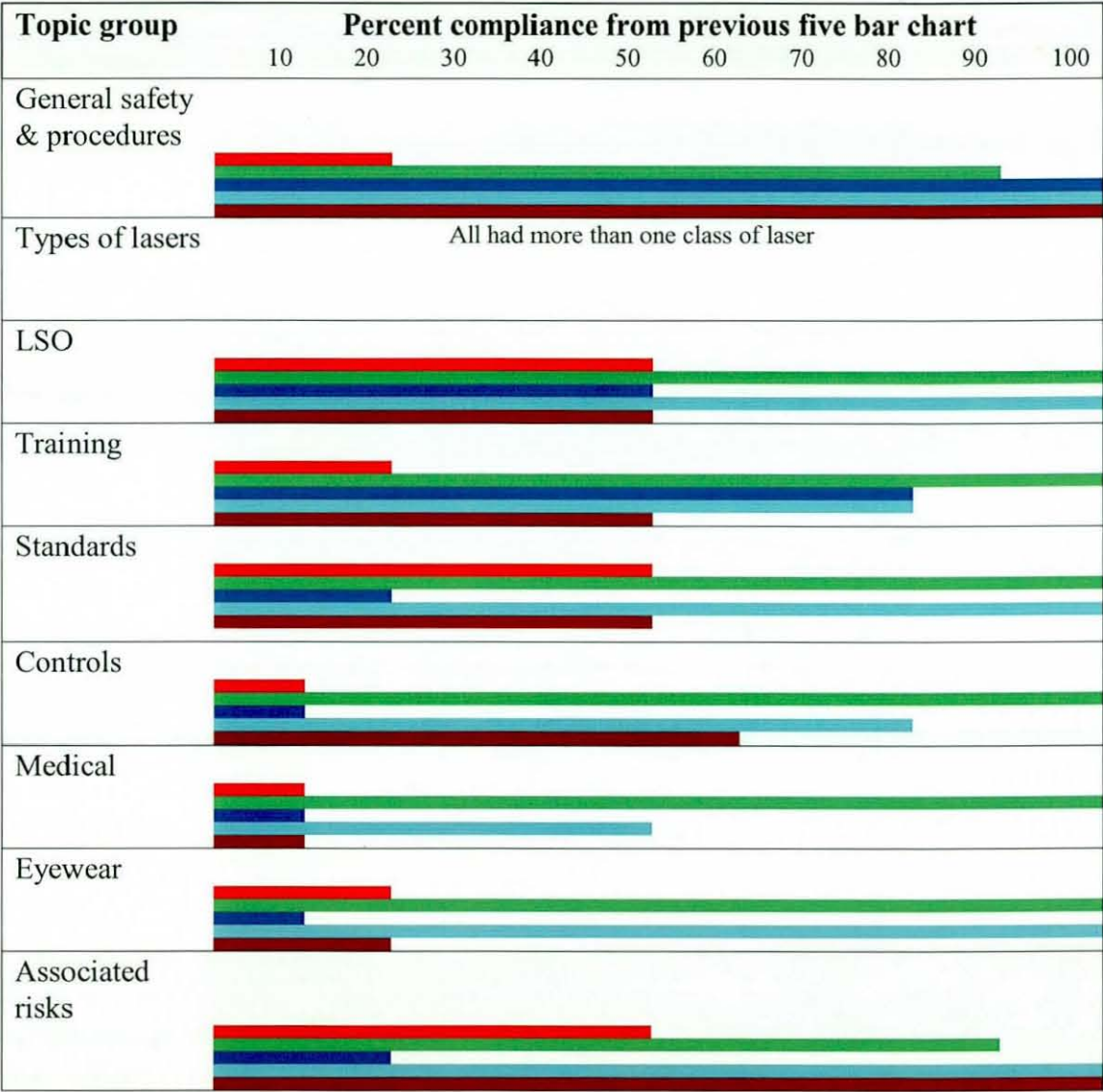


Figure 4.5 Chart of results from Entertainment questionnaire.



The figure 4.6 below shows the combined results of the surveys. Medical (NHS) show the best level of compliance and Entertainment (Displays) have the lowest level.

Figure 4.6 Combined response to survey questions comparing groups.



Colour code shade for positions of best compliance with standards and good practise.

Key



4.2.7 Summary.

The results follow the expectations of the LSOs who discussed the issue before the investigation. This did raise some concern of how well the survey reflected the actual situation or if the questions and style of interview have introduced a bias in the results. The 100% response in nearly all areas reached by the NHS indicated they met standards and good practise but does not mean there are not improvements that could be made. The comparison shows the range of compliance from planned systems with trained staff to, almost, as long as it works it must be OK.

The results from each area did vary over a range but the expectation that the permanent well-funded and regulated installations would be safer than the temporary, uncontrolled or unregulated did prevail. There were some responses that were a long way away from the normal level of their group, such as the controls and registration placed on laser pointers with a large research organisation. Similarly, one university had few of the required controls or training in place to support use of class 4 lasers by new undergraduates.

The common themes of 'poor access to solutions of requirements of laser installation' and 'poor support of the controls of system, to control use' were the key points that restrict improvements in laser safety. These findings support the idea that better, easier access to solutions that are easier to apply would allow safety standards to be improved. The associated benefit is that it takes less effort and resources to make a step improvement if the thinking and guesswork has been proved elsewhere.

This supports the requirement that the ability to search for solutions to laser safety hazards should be enhanced and those relevant solutions, which are easily available from a rich knowledge source, could meet this challenge.

5.0 CD trial - to improving the access to information.

5.1 Background.

In the literature review and during the research more information was identified as each area was examined in greater detail. The wealth of information found (57)(77)(46)(114) would support 80% of that required for safe laser operation, however it was not in one publication, paper or in a single area. The figure of 80% is from Technical Indexes (142) who produce, publish and distribute CBT on CDs or via the Internet on a variety of standards, safety publications and instruction manuals. The move in other areas of information presentation to electronic formats that can be searched for key words or topics which allow swifter access to information and solutions could be adopted. Following this technique several electronic formats were reviewed, including online, floppy disc and CD. The CD being a robust format that could be shipped with equipment is a good candidate. However it is fixed in time and better, more appropriate solutions may have been developed since. Information on the World Wide Web is often difficult to find or is not at the level or specific area of intent. (143) The choice of a CD rather than the Internet or other media is that CDs are cheap to manufacture and they can be shipped with the laser, so it will be available to the user when the laser arrives. The CD capacity is sufficient to contain a large set of information including pictures and diagrams far beyond the capacity of a floppy disc. Updates or more specialised information can be made available via a link to an Internet web site, which is discussed in Chapter 6.

The idea to use a CD for training and to provide some solutions to common laser arrangements came from the growing use in other fields of safety. (144) There are several support systems that are sold or provided on CD (145) to be used in the workplace. The speed of search and interaction that can be provided in the electronic form gives faster access to information, when compared with reference sources such as books or data sheets.

The information that can be provided on a CD could typically support 80% (142) of the common application of lasers. The initial scope is to have several sections and subdivide each into several levels of technical detail. This approach will allow the skilled person to access information quickly but also provide introductory basics to a new user.

5.1.1 Safety methodology.

The CD structure is following the safety assessment structure of identifying a boundary, identify the hazards, assess the risk, apply controls measures and review. This following the HSE guiding principles of ERICPD concept of Eliminate, Reduce, Isolate, Control, PPE and Documentation.(95) The specific laser hazards will be minimised by the initial control measures such as guards or interlock so that the PPE measures will be last and minor. The use of risk assessments will be outlined and supported by checklists of topics to consider. The application of this safety methodology is to consider the whole installation, as many of the laser aspects can be dealt with on a hierarchy of control measures.

5.2 Key structure elements of an information, safety and training CD

5.2.1 Elements to include or avoid.

The presentation of information must be attractive and easy to follow or people will lose interest and look elsewhere for the information or not look any further. (79) The government sponsored 'Virtual Learning Environments' (CBT and CAL) are in use at many colleges and universities through the 'Ferl information service' (146) which is part of Becta agency (147). This identifies that information should be accessible in a timely manner and in sufficient detail, the right amount. (148) The key points are that information should be present, each step as a single frame, that allows a person to go at their speed, to a comfortable depth of knowledge, is a superior learning process than to group teaching by rote. (79)

The structure of information should allow transition from one area to another, to provide greater depth or linkage to adjacent topics. (149) Information has increased at an exponential rate, we need to be selective in what we know, and learn in better ways. Virtual Learning allows the wealth of knowledge in books to be used in an interactive, selective and timely way. (150) This endorses the benefits of CBT and CAL to assist and streamline information delivery to a person,

There are some design and style pitfalls of the computer page that should be avoided. A page that is difficult to read, due to poor colour choice, a background that overpowers the text or cluttered appearance put a person off. A simple layout with navigation bar, commonly at the side, is used in the majority of cases. The software used to author the page can cause problems if it is viewed on an incompatible browser or incorrect resolution. Links to other sites should be structured in groups. However extra add-ins and unnecessary animation's should be avoided.

Available CDs of safety information in common use, by a number of colleagues, were examined in chapter 3.8.2 which include:-

- HSE Guide to the essentials of electrical safety, (112)
- Schmersal industrial switching systems, (102)
- EEF Display screens regulations, (109)
- IEE wiring regulations, (101)
- Radios Spares components (110).

These sets of information were also available in paper format, which would allow comparison trials.

Several templates were designed, which were discussed with the LSOs, who gave constructive comments on the structure proposed and the additional items they felt should be included to make the best use of the information. This iteration was followed three times before the first trial to test and review the benefits and shortfalls of the CD. The general structure had been identified during the literature review and assessment of the available safety CDs. The following sections describe the structure, levels, navigation, format, level of detail and computational support, of the first CD.

5.2.2 Design and requirements of trial CD.

The design of the CD was based on the 'include and avoid' (151-158) structure and layout identified in table 5.1 below. To enable effective access, the user must be guided to the information they require by several routes, so that if they are unfamiliar with the topic, they can still get to the intended information. Navigation by menus (forward and reverse sequence of slides) allows links between connected topics to be simple with the layout in a consistent manner. The ability to search and index the whole CD allows direct access to key words or items.(146)

The introduction section describes the content and the way it is arranged, to give the first time user an idea of what information is available. The preference to click to move around a screen rather than scroll up and down is generally preferred. (79) The size of picture and animation was minimised, as older computers take longer to load and if a person's interest is lost, then the benefits of the colour picture or video are also lost. (79) Table 5.1 below lists the features to include and those to avoid when developing an information CD. (151)(154)(158)(159)

Table 5.1 Features to 'include or avoid' on safety CD

<u>Include</u>	<u>Reasons</u>
Menu	Shows content and aids navigation
Hyperlinks	Can jump to relevant information easily and quickly
Small picture files	They load faster and can quickly show information
Several levels of detail	This allows levels of information from simple to in-depth to be accessed at will.
Photos diagrams where aids understanding	A picture can convey complex ideas quickly
Calculation section	Supports to assessments such as NOHD
Written in Java	This allows portability to several software platforms

<u>Avoid</u>	<u>Reasons</u>
Dark detailed backgrounds	These can make it difficult to see text or navigate the page
Un-necessary animations	They are distracting from the written text and should not be used unless they support understanding
Very long pages	People find it easier to understand chunks of information.
Dead ends or under construction	Always frustrating or feels a waste of time
Un-necessary video	Usually takes time to load very large file size, should be relevant (bespoke).
Many links to other sites in the text.	Distracting to read though this depends on the style of the hypertext link
Reproducing the standards	If it adds nothing, then just link to the standards.
Avoid bespoke software packages	Often will only run on limited types of systems or not all functions are available.

This identified the style features of CD that were adopted as the information was arranged and linked during the development. There were some variations tested such as a text only version (without pictures) which when reviewed was rejected as only giving half the story. All subsequent version all include pictures.

5.2.3 Three levels of competency of users.

The three levels of user: basic, intermediate and advanced were discussed in the literature review and have been applied to the structure of the trial CD. The three levels considered are to address the range of information needs of people from new starter through to the expert user. The shape of the CD format has been developed to a 3 level matrix, across several areas of application. This follows many safety structures (160) examined during the literature search. Several other CD based training packages

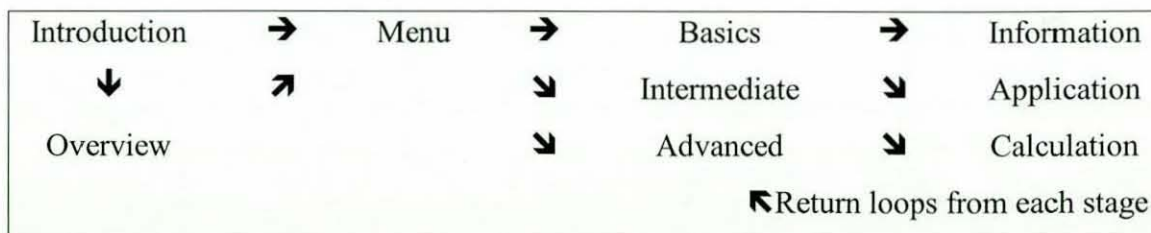
(73)(74) and the BBC (British Broadcasting Company) (105) safety training for staff that is produced on CD, all build on the awareness, operator and expert levels of knowledge.

The levels have links in the particular parts that allow the level of information to be moved through to give greater depth or a more simple explanation of the particular topic. This will allow people to move to a level of information that is suitable, if that particular part is not in their area of knowledge/expertise. This satisfies the requirement to find the right information in sufficient detail in a timely manner.

5.2.4 Navigation and directory structure.

When started, the CD has an introduction, which leads the person through the options to look at applications, theory or types of laser and at what technical level. There is a well-developed index of items and glossary of technical terms and descriptions. The individual pages are linked to allow progression through a topic and up and down to reach other technical levels. (146) as shown in Figure 5.1 below.

Figure 5.1 Pathways through information levels on trial CD



There are navigation buttons, topic tabs or pull down menus on each page, that allow the user to move to another topic directly rather than having to move back along a topic to a main menu and then take an new branch. This format has been the most frequent seen in the 'top ten of web sites' as voted for over the past 5 years. (151) This follows advice and guidance in publications such as FrontPage web design, (157) 1st Page web design,

(158) Dreamweaver (159) internet site design and Creating Web Pages for dummies (154).

Table 5.2 Layout format of frame in trial CD.

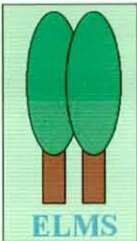

Slide logo	Title of slide and reference number
Home	Picture and up to 40 words (154)
Menu	
Index	

The layout was planned to be a balance of pictures and words. As many people do not like reading from a computer screen, the picture will help convey the information. (154) This could be a diagram of the suggested interlock that could be used on a high power laser installation. (154). As there are so many uses and arrangements that a laser can be used in it would not be possible to cover all of the applications. A selection of the common arrangements and some typical solutions would be useful to people. The number of applications can be added to over time with suggestions / feedback to improve the knowledge base.

The screen image figure 5.2 below is from the first trial CD developed as part of this thesis. This has been produced following the recommended criteria, including menu, forward backward buttons, small picture files size at several levels, index and calculations. This particular page is a navigation page on hazards that lists theory, controls, hazards and examples on the left with the more specific list on the right.

Each of the subsequent slides, has a specific topic of burns or eye strike as indicated, with a picture of hazards and links to the more in-depth pages, elsewhere on the CD. Title page and back buttons are on the left, the user can move about the detail and levels of the CD.

Figure 5.2 Layout of web page from CD showing navigation structure.

	B50 Hazards - basic level List of pages
B20 – Theory, safety, standards B30 – Engineering controls B40 – Procedural controls B50 – Hazards, safety B60 – Examples Back Title page	B51 - Laser eye strike skin burns B52 - Eye strike, long or powerful B53 - Laser strike, skin burns = = = =
Metal cutting With goggles to protect eyes(good) but no gloves/face shield to protect skin (bad).	

5.2.5 Format and style of trial CD.

The design of the CD had the following intention, that the format and style of the pages should be clear and clean with minimal words as a starting point. Hypertext links can take you to a page of text or work instruction that could be printed or read. The first pages should be snappy and concise, as people will click pages to get to the specific information but prefer not to read volumes of data from the screen. Picture, diagrams and simple animation can convey far more detail than words in some circumstances.

(147)

A glossary of a typical application that can be viewed either as stills or automatic sequence of views allows the user to look at the aspects that interest them most. An additional feature was to have a demonstration function that took the user through a sequence of pages that cover the breadth of applications and at various levels. This would be useful for a first time user if it lasted for 5 – 10 minutes. (155)

This follows similar lines to the BBC CD (105) that has video clips of a scenario that is followed with explanations and feedback of the appropriate actions and response to keep people safe. The Institution of Chemical Engineers On-line testing risk base training (156) is similar although on other safety aspects.

5.3 Development of the content of trial CD

5.3.1 What should it cover and what is needed?

Ideally it should cover what the user wants/needs to know but in a structured format that is progressive and addresses aspects in sections so that related parts are together and lead to a solution or answer to the issue. It would not be possible or useful to cover all of the applications and techniques related to lasers, as they would always be incomplete and retrospective.

The scope for this trial is to include three main topics, which are information, application and calculation.

- Information is for learning about lasers and the types of lasers,
- Application covers what they can do, how they can be used safely and controls applied,
- Calculation is necessary, as there will always be the case to cover unusual or emergency situations.

5.3.2 What should / do people want to know?

Often people want to know the answer to a specific question, such as,

- what type of laser can produce a certain wavelength?
- what class is a certain power laser within?

These can be searched for in the index, contents or word search function. The next question asked is likely to be,

- what controls?
- how should they be applied?

The CD shows several typical applications and the controls that should be applied to safeguard the operations.

5.3.3 How much detail?

The layers of information will allow a person to move up or down in levels of detail. If it is a specific topic with specialist groups a hypertext link can go to an associated topic or further explanation. The use of pictures and video should reduce the amount of text required to cover a topic as people are reluctant to read pages but can often get the information from a few minutes of video that they will take the time to view.

The video of a laser application will be more powerful in linking to the actual workplace and the controls that should be applied to laser use. The size, shape and ideas to apply controls can be seen and copied or adapted as the thinking part is less, as a solution is shown rather than words requiring interpretation. (104)

Figure 5.6 Layout structure of topics on Laser Safety CD produced for this thesis.

Introduction			
Title page			
A How it works	20 Theory		
	30 Engineering controls	21	
	40 Procedural controls	22	
	50 Hazards	23	
	60 Examples	24	
		25	
B Basics	20 Theory		
	30 Engineering controls		
	40 Procedural controls	31	
	50 Hazards	32	
	60 Examples	33	
		34	
C Intermediate	20 Theory		
	30 Engineering controls		
	40 Procedural controls		
	50 Hazards	41	
	60 Examples	42	
		43	
D Advanced	20 Theory		
	30 Engineering controls		
	40 Procedural controls		
	50 Hazards		
	60 Examples	51	
		52	
E Calculation index	10 Index		
	20 Calculations		
			Return menu from all pages

Starting at 'Introduction' on the figure 5.6 the pages lead to the 'Title Page' that allows the user to choose the level they wish to view. Each sub section, 'Basic', 'Intermediate', 'Advanced' has the same sections of 'Theory', 'Engineering controls', 'Procedural controls', 'Hazards' and 'Examples'. The last two sections of 'Index', 'Calculations' and 'End -Return' allow the user to search and move between sections.

It should be understood that in no way is the CD implying that the information is not presently available or that people can not get to the safe solution if they have time and support. The solution offered is to encourage people to use time and resource to apply a solution rather than be put off, having to design it or interpret standards. If it is easier to do it is more likely to be done. (150)

5.3.4 Training information in the trial CD.

A selection of pages of this CD gives training and awareness of how a laser works and the safety requirements. Awareness information is a package that was provided with a test to establish basic awareness/competence. This should not be extended to the LSO level as the application and underpinning knowledge can not be effectively tested, due to wide range of fields of experience. The same tabs can be used for reference and link to further information. The typical competence levels for user, operator and LSO can be described, which will assess people to understand the responsibilities and roles of the levels.

Computer aided learning (CAL) and computer based training (CBT), acknowledges that some awareness or refresher training at the basic levels can be accomplished with the use of computer programs. There are several software program packages referred to in other parts of the text of the CD that can be accessed via the Internet. (135)(74) It maybe appropriate, depending on the feedback from testing, to include a similar training/learning package on this CD or point users towards the other sites. (77)

The benefit of a basic awareness program would be that the users in a company could all be brought up to the basic level. It would then identify and assist that future training should be provided for higher levels within the group. This could be fulfilled with a link via the Internet at a later stage.

5.3.5 Search function and index.

- Search function.

It is useful not only to have a search engine that will search on key words but also link common questions for a topic.(151) It takes more time to develop a linked system but it could be on the basis of a fault tree that leads the reader through options of control measures descending in safety from the best to provide a range at various levels of complexity and cost.(152) The hypertext links can have menus of items that allow a choice of related items so that the most relevant can be chosen to get to the key information more quickly.(153)

- Index and contents.

There should be an index in alphabetical order as well as a contents list to give the user different approaches, to allow them access to either a particular item or topic of interest.(153) A map of the CD contents can be of use to see the flow of information so that the first stages can be bypassed on subsequent use or to go to a topic area that may be developed in later editions.(151)

5.4 Trial and review of CD

5.4.1 Trial of CD with Laser Safety and other safety offices.

The laser safety CD developed as part of this thesis was tested by third parties to get objective, independent feedback. The software has run on other computer systems and has been used successfully to support learning and check calculations. It does stand on its own and has been supported to run on older PCs.

The testing was in several stages to prove the access and links between pages. The flow of information was confirmed to be in a logical sequence and correct in that it agreed with the standards and requirements of regulations. The people who tried out the CD

were either given instruction and description of the contents and how to use the system or left with the CD to confirm if the organisation and links were intuitive. The table 5.3 below shows the number of people who would use the CD, found it useful or would not use the CD because they would ask a LSO.

Table 5.3 Number of people who would or would not use the trial CD (N=20)

	Safety staff	Laser staff	Total
Would use the CD and found it useful	2	3	5
Would use the CD	4	5	9
Would not use the CD but ask a LSO	4	2	6
Total	10	10	

The figures of 6 “would not use” and 9 plus 5 that “would” gives a ratio of 14/20=70%

The feedback of what else was required or should be included the following requests:

1. Improved calculation function with examples.
2. More specific examples of hazards.
3. Available on the Intranet to improve access.
4. Improved graphics
5. Interactive testing for CBT refresher.

The CD has been used for laser safety awareness training and has been accepted as of a similar level to the classroom training normally given. The controls identified on the CD have been used as a checklist during audit of an existing laser system that has been approved as adequate.

5.4.2 Review of trial of CD.

Feedback has been assessed and modifications can be made to include some additional information and some worked examples of calculations. This has been requested as it will help the decision process to decide on values of beam size and assumptions regarding source size and power variations that can make a difference to output levels.

The CD produced does not fit all of the requirements (physical arrangement of interlock systems) that have been fed in due to time or cost constraints. It has been confirmed from written feedback that it does hit 70% of the requirements of groups in the trial. This is short of the 80% identified at the beginning of the chapter. There are always the special cases that should be pointed to the standards, a learned body or consultants for help. Further development can capture these cases in time.

There has been some negative response from some laser staff who supported the trial, that the CD detracts from the standards or it does not replace the training courses, but the CD should be seen as raising the awareness of more people. That the CD can bring in more requests for training and assistance with special cases is a strength.

The trial was monitored by those who are already trained as LSOs so that they could say if it was good support or not and that those who were outside the laser training if they now understand the requirements of the standards. The feedback was that it provided good support and the standards were better understood but not completely so. Also that wider knowledge of the application techniques for laser power calculation and adjustment factors is required to use the calculation tool correctly. When assessing the mode in which the laser can be used, the most powerful must be identified, so that the correct value is used to define the controls and protection requirements.

5.5 Should it have calculation and formulae in it?

There are some software programs (69)(77) that give basic calculation models for laser power levels. (70) These do need experience and understanding of the laser power,

damage mechanisms and specific physical values. The calculation could either give very conservative values or give values that would cause injury because factors had not been taken into account such as pulse rate or general light conditions that change pupil sizes. Learned bodies can provide more information and advice on safety calculations.

For people with sufficient knowledge to apply the values in the standards to actual equipment arrangements, the second trial CD has a calculation section that will perform the calculations from a few input parameters to avoid possible errors in calculating the values in each formula. Computers can calculate the value and remove possible errors of reading the wrong value, which will allow people to get past the barrier/concern of calculations, to what does the answer mean and is it safe. The output value for a type and frequency of laser can have a text phrase, confirm if it is below the MPE hence safe.

The calculator that was added had a highlighted statement that knowledge and practise is required to assess the value of laser energy. If in doubt advice should be sought for a qualified LSO. Some examples highlighted the errors that are commonly made *regarding measurement at incorrect distances and not testing for compliance with the most restrictive requirement at certain part of the MPE matrix.*

5.6 Further development of CD

The CD produced has been further developed to meet some of the requirements described in the review in this chapter. The information detail and number of examples were increased but did not provide the range anticipated. It was realised that the CD will only be able to provide a proportion of the information requested and is fixed in time. Additional information to develop from the industrial area to all main uses of lasers can build onto the theory with controls and applications to the medical and research field achieved with a modest enhancement. This would then allow the CD to be used throughout the laser community that could support the application of standard solutions and training. This would bring cost benefits to the users and common standards that the manufacturers can then apply during manufacture.

The two groups that could provide the greatest support are the Universities through the Vice Chancellors Safety Committee and the Association of Industrial Laser Users (AILU) applications group. These two groups have many members and are spread across the country. This would enhance the peer support and interactions to develop common standards for controls and training. It could be a timely update of the Southampton laser safety video (161), that moves to a comprehensive, risk assessment approach to hazards in equipment, that includes a laser, which are not just based on the radiation issue but cover all the safety issues.

5.7 Summary

The information must be easy to find, attractive and relevant to the user, which will make it more likely to be taken notice of and applied. The CD produced does not fit all of the requirements due to time or cost constraints, only achieving 70% of the 80% established by the groups in the trial. There are always the special cases that require further development, which will take time to capture. Some negative response from staff who supported the trial was that the CD detracts from the standards but it was seen as strength that it raised people's awareness of hazards. The trial was monitored by staff familiar with the standards who feedback that the standards were better understood but not completely so.

The original idea to use a CD format to address the requirement of solutions for numerous applications and configurations was not feasible, due to the high number of variables and arrangements possible. Table 5.3 shows that only a proportion of staff would use a CD to find information with other arrangements for inspection or monitoring being superior. The trial group had a high proportion of safety staff, so the proportion would be even more dilute in the general workforce case. The range of applications, changes of technology both power and efficiency coupled with short pulses are continuous hence the CD would always be requiring updates. As the CD is limited by the information available at the time, it would benefit from an Internet link so that updates can be accessed as equipment develops and to use other good solutions that are posted on the World Wide Web.

After further review it was concluded that this is not the answer. The CD is an electronic book that provides answers more quickly but is not specifically detailed for an individual case. A search system that has links between topics and is grouped to guide a person to a solution is preferred. During the trial the requirement to be able to find the solution to one specific bespoke problem was requested. Internet access will improve the scope of search and allow updates with development. The search function should develop as the application increases and more solutions are identified. A smart automated development tool for the Internet could provide this function. Several universities have developed search engines that build connection to rules that can be honed to improve the quality of the search function and selectivity of the results returned. This type of search system is based on a structured listing taxonomy or ontology that can provide superior results.

The option of a CD was concluded with research then moving to identify/develop an Internet based search system using a structure search tool to provide wider response to answer specific questions.

6.0 The proposed solution: Informatics, Ontology.

6.1 Introduction.

The previous chapter trialled an exemplar CD which did not fulfil all the diverse requirements of a multi user base. It needs to be dynamic and able to thread across into related areas. The experts involved with laser safety standards often view the hazards from the laser perspective that does not take account of the information of other hazards or risks, so they do not address all of the hazards. (24) A better search system to access the wider knowledge base through the Internet is required.

If layers of information are obtained, they are more easily refined, to capture the specific topic and hazards associated with that segment. Safety legislation is arranged in top down layers. This has been navigated to obtain a fresh view on the requirement to make laser use safer. An example is the guarding that is required to prevent exposure to foreseeable radiation in BS EN 953. BS EN 60825-4 only addresses direct laser radiation where there is clearly a requirement to take account of all hazards and secondary reflected radiation. It has been identified that information and specifically legislation are grouped in layers that are used to expand from a central theme to specific detail of individual parts. In the case of legislation, acts, regulations and standards can be viewed as a pyramid such as figure 6.1.

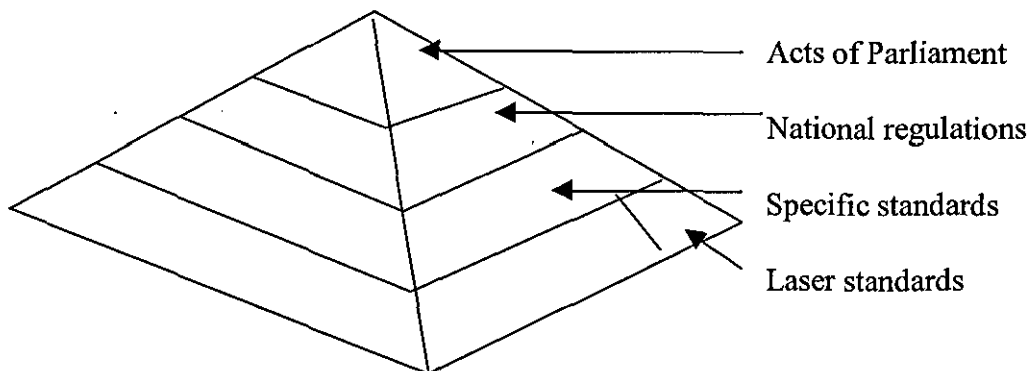


Figure 6.1 Diagram of general safety pyramid.

The figure 6.1 of general safety above shows layers of legislation, standards through to the specific laser standards. This allows a view to identify the significant hazards, include the laser, rather than only the laser radiation hazard.

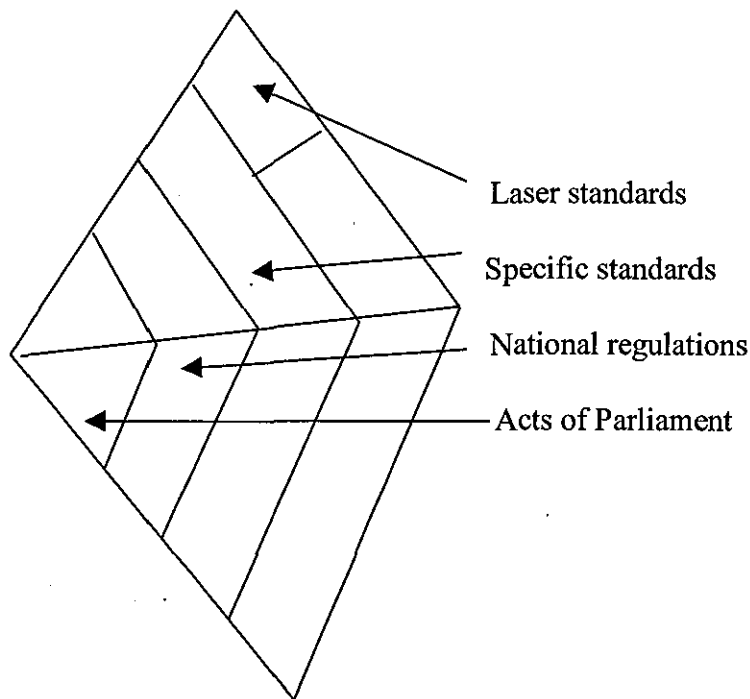


Figure 6.2 Diagram of laser safety Pyramid.

If the view is with optic laser radiation at the top as in figure 6.2 above rather than general safety it gives a different and unbalanced view of the significant hazards present.

The figure 6.3 below has coloured circles relating to hazards associated with lasers assuming the same level for each hazard. The left hand view of the circles has laser optical safety viewed as seen by laser safety specialist and the right hand view of the hazards viewed by a general safety person. More of the blue circle can be seen representing the larger hazard in the laser optical safety view point than the other hazards. The perception is that the optical hazard is the most obvious, however from the general safety view point all of the hazards look the same size.

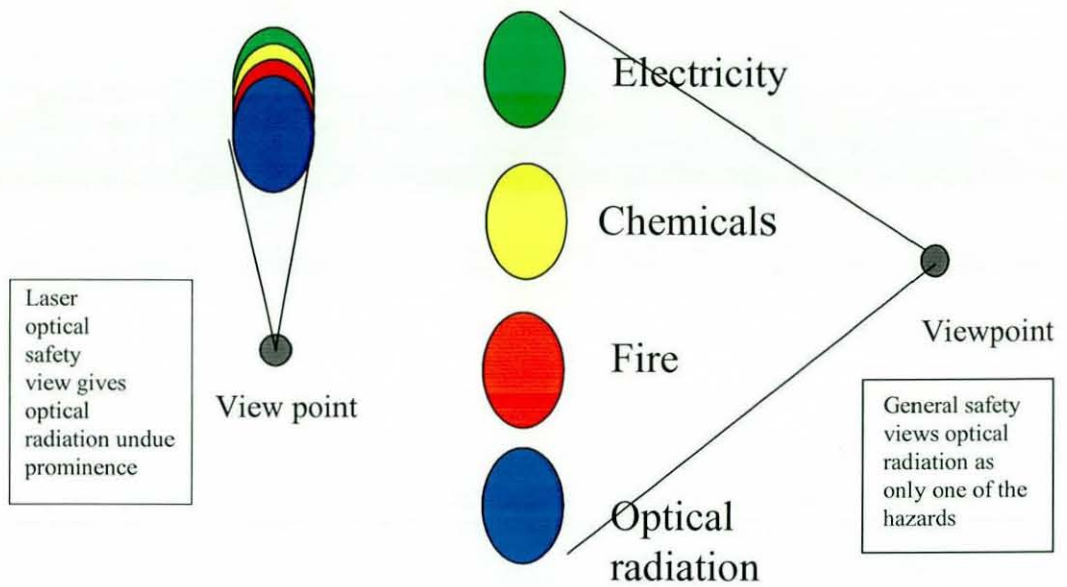


Figure 6.3 Figure of alternative views of hazards associated with a laser.

Searching the hierarchy of legislation and standards can be with a structured search engine underpinned with a linkage/focus of safety. The results will link the hazards, safeguards and lessons learned from previous incidents. The information of hazards and how to improve is already on the World Wide Web, although it is not in an easily accessible format at present. (Chapter 3)

To access this information, on the World Wide Web, two systems need to be developed:-

- 1) Mapping the laser safety knowledge, linkages and attributes.
- 2) A route to search and arrange that knowledge.

To map the knowledge it is necessary to structure or provide an information framework to work with. This will depend upon the format of the information and the route and protocols to gain access. It can range from extracting information from tables through to translation between software languages or spoken languages. (162). Translation of data fields and transmission of data using existing Internet web services enables access to far more sources of data.(162)

Existing databases or results from search engines provide the foundation for cataloguing by common term or term association. Relating categories and attributes of information can provide several routes to reach a knowledge statement. Keywords or adopted text that will be used for searches will form the backbone of the structure to access the information. This often requires modification as the knowledge base expands to accommodate new developments.(163)

A structured access portal of the Internet would allow better access to the knowledge that is already there and will provide access to information as it is added. The World Wide Web has been established since 1993 (162) as the primary source of information, however it has grown organically and hence has many idiosyncrasies that impede access and may be out of context. (164) The Internet has grown through enthusiasm to make a new idea work or through developed business needs. (162) These different drivers have given very different solutions. (162) As they have been developed software has changed and improved which has moved the foundations of databases and increased the gaps between systems. (163) This unstructured growth is impeding access to information.

General search software reviewed in the literature search, such as Google or Ask Jeeves, have indexes built that have been searched and established before they are used by the public. This allows fast access to listings and links to the sites. The search is influenced by the way the page is referenced using just the title or key words from the text. A further factor that influences results is sponsored links or rating based on number of times the page is accessed (hits). This supports the findings in the literature survey that searches on "laser safety" find "goggles" rather than interlocks or controls systems. The information is available but not easily recognisable so not accessible. The search system needs to be developed to navigate around the present search terms supported with better contextual linkage between search words. The general search engine does not distinguish between the meanings of the word BED. It could be a flower BED, laser machine BED or BED to sleep in, but the linkages in the enhanced search engine will categorise the meaning to allow effective searching. It has been recognised by the 300 member groups of Webonto (164), an information exchange for knowledge management, that there is a requirement and benefits of being able to tap into the vast amount of information on the World Wide Web. Many different systems and approaches

have been developed. Some of the approaches have taken different routes, which include 'Knowledge Base Systems', 'Artificial Intelligence' and 'Expert Systems'. These are used to collect information but do not always enable the correct sense or linkage between topics to be identified. (163) An advanced search system uses the context of the word and linkages to obtain more specific results. The structure of the search system has terms categorised and linked related to the context the search is to be applied in, so improved results are obtained. Classification of search terms can be in a taxonomy or an ontology.

6.1.2 Ontologies

Taxonomy - Classification.

Taxonomis are subject based classification that arranges the terms in the controlled vocabulary into a hierarchy.

Ontology – Philosophy – the study of the nature of being.

-- Philosophical -- the set of entities presupposed by a theory (Collins)

Ontologies are structured relationship links that are used by a search engine to gather information on the relevance of text on a web page or within a document.

An example of the importance of the linkage has been identified that a 'bed' could be used in the context of a place to sleep, where flowers are planted or the work surface of a laser machine tool. Software techniques have been developed to guide identification and improve data mining to search, link and refine information that is on the Internet. The software types range from developments of [http] mark up tags, metatags, through structured search engines, taxonomies to ontologies. Mark up tags are limited by the area they are stored in and the action of search engines. However it may only take a specific few tags, to increase speed of searches. Improved tags only give a guide to the information on a page and may be used to increase the traffic to that page for commercial reasons rather than accuracy of information. (166) The use of more effective search systems such as those using ontologies, that allow the text and meaning of the words to be searched for, obtain more accurate results. (162) Improved searching to

achieve specific knowledge will allow the gap of identifying all hazards associated with a laser to be addressed.

This knowledge capture will allow the short fall of information system identified in the early part of this thesis to be addressed. Semantic searching using an ontology is the most significant step forward in knowledge management, since the advent of relational database, which were in their day the step change from the original Dewey Decimal system. (163)

Development in other sectors such as Nuclear and Medical safety have made inroads to allow structure searches or automated information gathering and collation possible using ontologies.(163) The route taken by universities and user groups is to enhance the search engines used on the World Wide Web to search in context again with an ontology.(164,165) That the meaning of the words of the text, not just title of a page of information, is used to refine the classification of the search has been possible with an ontology. (166) As described below software search engine use the linkages defined to search web pages.

This therefore requires an ontology of safety, for laser safety.

6.1.3 Web robots and information agents.

To search the Internet, software is required to search, read, and interpret ideas and to record locations of web sites and their topics. This can be achieved with a web robot or information agent software program.

To address the requirement to interpret the information on a web site or page, there are benefits of reading the text on the page not just the metatags. Software (Bot2001, www-Robot0.021) is in use that can read the text and glean information on the frequency of key words or phrases. (162) A software program that can read text on the Internet and send back suitable information is called a web robot or information agent. These are used by large search engines such as Goggle and Alta Vista. However they have not yet been fully developed to interpret the sense a word is used in or information in diagrams

and pictures. Understanding or defining the sense that a word is used in is important to enable the correct sense and use to be established. This is the semantic link. (162)

A web robot is a program that traverses the Internet / World Wide Web hypertext structure by retrieving a document and recursively retrieving all documents that are referred to in that first document. The web robot (167) search engine can be assigned work so it will explore the web and search for relevant pages of information. Rather than just using the title or content in the metatags (168) to identify pages or a site, the web robot can interpret or match the text on the page to that required. The ontology will be at a high level, so that the style of a written page or translation can still be used to gain the sense of the text.

This then can provide a refinement that is many times better than even the natural language search engines generally available.(162) To search for information in safety cases and safety standards these ontology based techniques enable better communication of information for safety critical systems to be identified.(169) This provides commonly accepted standards of understanding and support, to identify and confirm that systems are effective and comprehensive so that the system can be endorsed as safe.

The Internet has grown freely and as such there are many standards and languages that require either a common standard or flexible interpretation. A vast number of computers run Microsoft Windows applications. However information held on databases and developed for posting on the Intranet are translated to HTML and its variations. To allow the present text to be searched ontologies of concepts and words have been developed to improve the accuracy and interpretation of text on the Internet. (162)

6.1.4 Structure of a safety ontology.

Many examples of ontologies are being developed such as Ontosarus browser by University of Southern California (USC) Information Sciences Institute (170) , a Java based browser by WebOnto (164) which has links to over 300 companies that are developing the use of ontology base search systems. Cyc Upper Ontology (171) has an ambitious goal of encoding the entirety of common sense. This is ambitious; however it

demonstrates the effectiveness of the approach. A standard, top-level ontology is being developed by an Institute of Electrical and Electronic Engineers working group.(171)

Given so much activity in this area, a strategy is to follow an existing ontology (172) that is based on medical safety issues and develops it towards the specific parts that address general machinery and then apply that to lasers. The balance should be assessed if the work to amend an existing ontology or start from scratch is the most effective route. The linkage between people, tasks, employment and finance are generally defined so that specific aspect such as risk assessment and hazard analysis can be built onto the common base framework. This technique can be efficient as it builds on a common base such as the IEEE listing. The use of a structured system to gathers facts, to get data, then meaning and understanding and finally knowledge with insight has been achieved in several areas.(162) This hierarchy moves from data to information, to knowledge, then wisdom.

Many organisations are developing ontologies (170) and using them to search the Internet and other databases to gather information that is specifically linked and in a structured sequence. The development is to establish common rules (163 166) so that those people who code or arrange pages, interpret systems that will allow the broad search of the information from many view points. This allows the information to be gathered that is specific to the question rather than having a few vaguely connected returns or several thousand that then require extensive refinement to get to the solution.

To develop a safety ontology that includes machines and lasers, a higher level structure has been developed. It starts from legislation, through a general safety base and is extended to include specific issues associated with lasers, such as electric shock, fumes, toxins and the light hazard. This structured model follows the sequence of the HSE 5 steps to risk assessment which is used throughout health and safety.(173) The components that were identified/developed for an identified system are:-

- identifying the hazards,
- decide who might be harmed,
- risk assessing them,
- controls of elimination, engineering and then procedural to minimise the risk.

- review and revise is necessary

These elements were initially grouped in a taxonomy to support the development of the ontology. The grouping was refined to obtain the root classification of a group and then supported with distinct sub classes that were children of the main class.

The linkages and attributes were then associated with the classes. This process was repeated to refine the input, links and outputs. This included identifying who can be affected by the laser, what could happen (knowledge from previous accidents), what likely issues should be addressed. Solutions to the hazards may identify training and actions that should be put in place. This structure has to be robust to achieve developed linkages so that they can be searched by a web robot. The subsequent layers of greater detail or more specific information can be developed so that the refined search is possible. To achieve the correct sense and inter-linkage between the issues the higher level framework is required, otherwise the general safety and laser safety island (figure 1.1) will develop separately. To demonstrate this theory, examples have been developed that follows the 5 steps to risk assessment from general safety to then consider the specific laser aspects.

The specific linkages and relationships within the ontology can be built on a basic safety ontology with specific additions to take account of the variations of machines and lasers. The key for laser safety is that the search is from a general safety base that accounts for all hazards including lasers. This also will provide support to meet the Acts of Parliament, National regulations through compliance Standards to specific standards including lasers. As the search can be performed at any time the information is up to date.

The web can be accessed continuously, reports back on developments or updates can happen when they occur or at set periods. This approach takes the benefits from 'experts' and 'knowledge' that is on the Internet and from related/similar topics that brings breadth and alternatives to be considered/adopted.

6.2 Developing ontology

6.2.1 Exemplar ontology

There are many companies developing ontologies, which can be used for a wide range of purposes. The safety ontology for lasers should start at a high safety level and so it will also provide the search vehicle for many other areas of safety. The ability to develop improved access to safety information, linked to legislation, is a key development that has opened the way to provide effective solutions to the workplace. (164)

Many ontologies have been developed to link between high level concepts and machine code application software (162). To develop a structure from concept through design to implementation, several steps are required. This allows the development of an idea through a structured design process to achieve a robust, reliable code or file. A model of the layers of software and/or semantic link must be established.

Table 6.1 below shows the conceptual level on the left with the corresponding links to the modelling language and the Java coding on the right. This has the advantage of using a Java based system, which has portability i.e. that it will run on multi-platforms. The concept, relationship, constraints and instances below define the relationship between the items to define their sense and linkage. This structure is the translation from the concept level through design to the software code so that the grouping of items and then the linkage between them are arranged in a consistent manner. This is so that the sense of the relationship and attributes are constant between groups.

Table 6.1 Relationship structure of a conceptual ontology.

Concept		Design		Software
Ontology		Unified Modelling language		Java beans
Conceptual level		Design level		Implementation level
Concepts	↔	Classes	↔	Classes
Slot relationship	↔	Attributes	↔	Properties
Constraints	↔	Object constraint language	↔	Parsed
		Constraints		Object constraint language
Instances	↔	Instances	↔	Instances

This is the conceptual view of ontology and its representation with Unified Modelling Language (UML) class models and in an object-oriented language such as Java. (162)

Concepts classes ~ graphical display related to the algorithms implementing the system.

Slots attributes – classes relating the abstract ontology.

Constraints – expressions corresponding to attributes and classes.

Instances – from the knowledge base representing the diagram classes.

There are some broad ground rules for developing an ontology. It is a developed database with descriptive groups (classes, slots, facets) within a domain. There is no one way to develop the domain as it follows an iterative process. However the relationships between the levels and whether the attributes are concrete or abstract should adhere to the established convention. Each element has a relationship defined and properties attributed to the items that may be different at alternative levels or inherited. The scope and key topics should be identified as this will determine how detailed or general the ontology is going to be and so will guide many of the modelling decisions.

The following questions were answered to confirm the requirements of this ontology.

- What is the domain that the ontology will cover?
 - Safety, Laser Safety
- What is the ontology going to be used to provide?
 - Safety requirements and solutions.
- How should the information/answers in the ontology be arranged?
 - Topic or power.
- Who will use and maintain the ontology?
 - LSO's or a central authority

Once the broad scope was confirmed the next step was identify the flow of elements.

- defining classes in the ontology,
- arranging the classes in a taxonomic hierarchy,
- defining slots and describing allowed values for these slots,
- filling in the values for slots for instances.

The detail was then added throughout the dataset. The development of the coding should be based on existing ontologies and then expanded to cover general safety. Subsets in the coding, such as fume and hazard can then be included in the middle layer to link between them. The resource to develop a new ontology should be weighed against the depth of development of other existing ontology listings to decide which format to follow. Several ontologies (Kaon, Protégé and DAML+OIL) were explored and the first two developed to trial the conceptual structures. DAML+OIL was not well supported, it did not have tutorials or examples.

6.2.2 Kaon and Protégé software development.

The trials of several software packages confirmed that Kaon and Protégé were more developed and have available examples of coding. There are several examples on the Internet that can be downloaded and tested to understand how the classes link and how

to develop any ontology. Development of working models using both software packages, as shown by the screen shots, has been part of the research of this thesis.

6.2.3 Kaon.

The first package developed was a Kaon workbench (163 164). This is a graphical package where elements are added and linked by drag and drop. In common with both development trials the base classes, group of items or concepts were developed and then the specific instance of information added to each class. The final step was to develop the linkage between instances or classes in either concepts which are fixed or properties that can vary on each instance. The ontologies were then tested to produce answers to queries to check the linkages between items before they were used to search for information to answer the questions. The results are given at the end of this chapter.

Screen shots are shown on the following page. The first figure 6.4 shows the starting point where each of the boxes is used to define the linkage between elements such as classes, concepts or instances. The boxes show and can be used to define the hierarchy and connectivity between elements. The second screen shot figure 6.5 shows the expanded graph of the structure and its relationships. This graphic interface allowed the view to be expanded to see greater detail or rotated to view the structure from an alternate key node to understand the interrelationships. The linkage and relationship can be viewed but there has not been a text output established to enable a question and answer protocol to function. This can be added but was fundamental to the software development of the package rather than the semantics of the knowledge base.

Figure 6.4 screen shot shows the main Kaon development page
(Main development: the central node kaon:root and sub-concepts in the box below it)

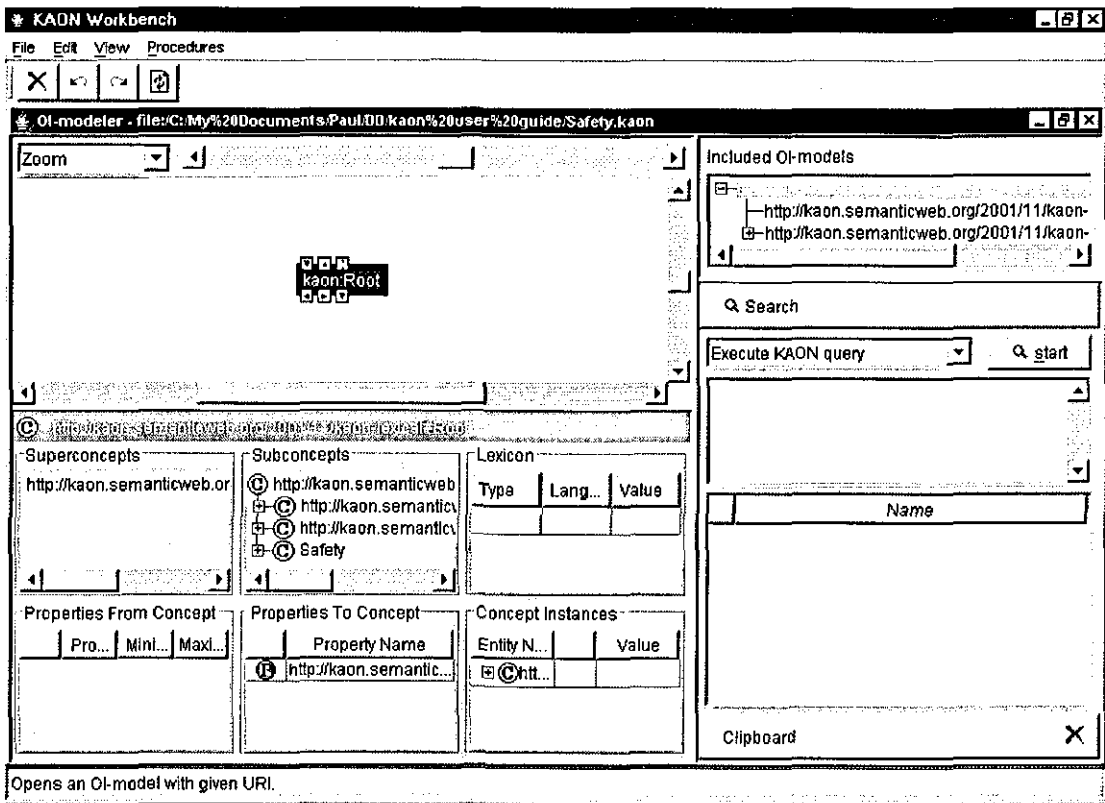
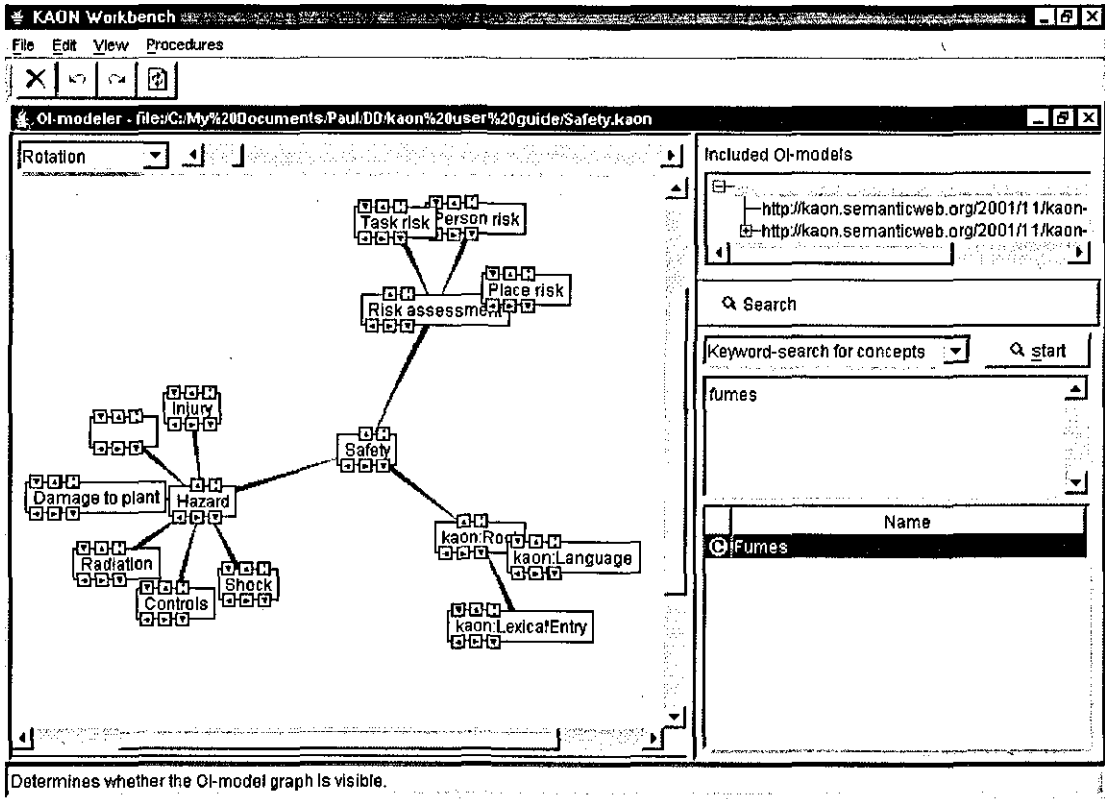


Figure 6.5 The expanded link/structure of the ontology (can be rotated or enlarged).



The minor nodes (hazard and risk assessment) can be rotated around the central node (safety). The zoom function would allow closer views or overview of the arrangement. The level of detail and attributes of each node has tabs that can be clicked on or off to view attributes, links, domains or class information. The graphic package allowed several views but the interface linkage to text had not been developed. This was a major disadvantage of this package.

6.2.4 Protégé.

The second package used was Protégé (174). Several updates were published during this research period. Protégé is an integrated software tool that was used to develop the knowledge-based system that was used in problem-solving and decision-making in the laser safety domain. Protégé-2000 is designed to be easy to use and to allow reuse of domain ontologies and problem-solving methods, which shorten development and program maintenance. Protégé maintains two files in addition to the pprj file; these files contain further information about the ontology and instances of the project. Applications can be executed within the integrated Protégé environment.

The laser safety ontology defines the set of concepts and their relationships. The knowledge-acquisition tool is designed to be domain-specific, to support intuitive construction of the knowledge base. The resulting knowledge base was then used with a problem-solving method to answer questions and solve problems regarding the domain. The initialised knowledge base was created in the system class rooted in :THING, no instances were created at this stage. Following this step the project classes and slots were created. Finally, the application is the end product created when the knowledge base is used in solving an end-user problem employing appropriate problem-solving, expert-system, or decision-support methods.

Earlier versions of Protégé separately defined classes of information (schema) and stored instances of these classes. The later version of Protégé makes it easier to work simultaneously with both classes and instances. Thus, a singular instance can be used on the level of a class definition, and a class can be stored as an instance. Slots were elevated to the same level as classes, so that the new knowledge model conformed to the

Open Knowledge Base Connectivity (OKBC) protocol for accessing knowledge bases stored in knowledge representation systems.

The parts are accessed through a uniform GUI (graphical user interface) with overlapping tabs at a top level to provide a compact presentation and convenient co-editing between them. The tabs enable easy transition between the modelling of an ontology of classes to describing a particular subject, the creation of a knowledge-acquisition tool, to enter the specific instances of data and creation of a knowledge base, and to execution the applications.

This development was with the support of good tutorial explanations and several examples of application, such as ontologies of articles in a newspaper and another of wine selection to compliment various foods. This was developed in the same order as the Kaon model. The development planning of a knowledge-based system is more of an art than a science. There are some standard approaches a new user can follow to avoid common problems of systems development. Construction was an iterative process where several cycles of revision are required to create the ontology and aspects of the knowledge-based system. The steps to develop the ontology included:-

- Identify the problems to be solved with knowledge-base technology.
- Building a small initial ontology of classes and slots, to view the forms and classes.
- The forms have slot values applied that allow the expected range of values.
- The knowledge-base was tested during construction to confirm it aligned with the application and problem-solving method employed. The full test of the application with the end-users prompted further revisions to the ontology and the knowledge base before it was completed.

The view in figure 6.6 shows much of the taxonomy of classes used to establish the structure. Each level can be expanded to see the sub classes of each main class. The linkage of the highlighted class (fumes) is shown on the right in template slots. (health, damage, harm, injury) These can be development or amend during development.

Figure 6.6 Classes (left) have been developed from the 5 steps to risk assessment

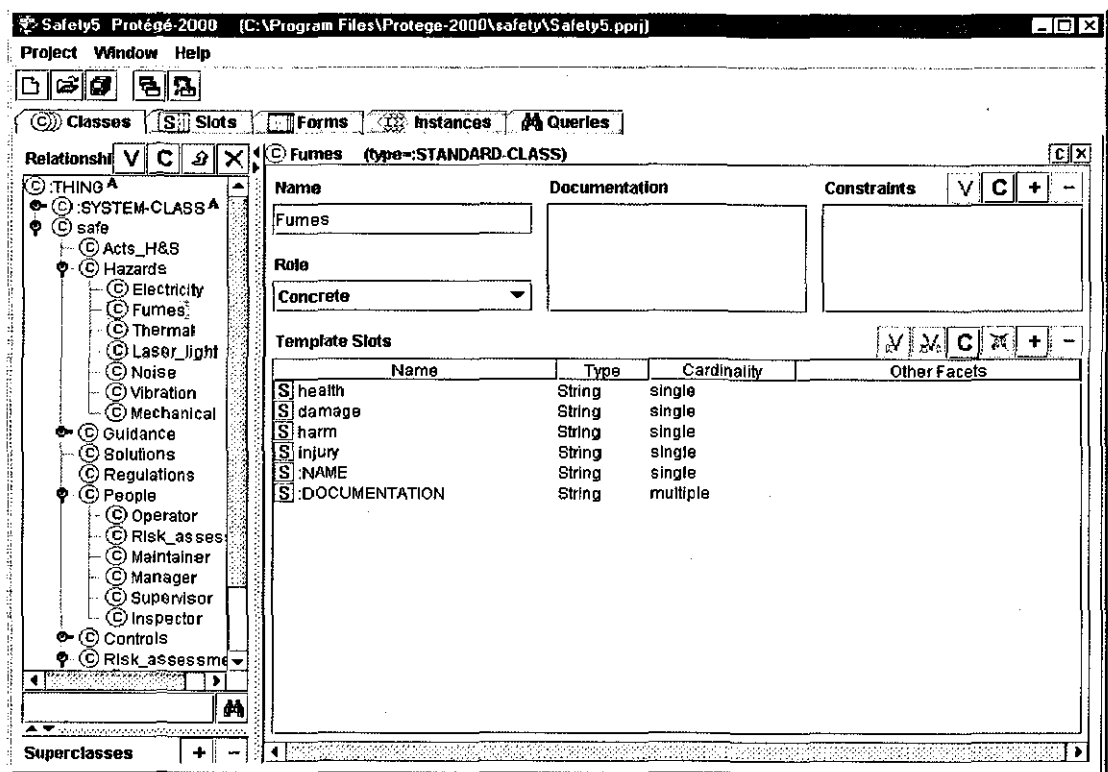


Figure 6.7 below shows the attributes of each instance associated with a term (solutions/class 1) can be listed in tables to provide a range of linked terms and related attribute. There are functions to copy, cut, paste, select from menu or index that supports rapid development of the attributes and linkage.

Figure 6.7 The instances tab for several laser classes.

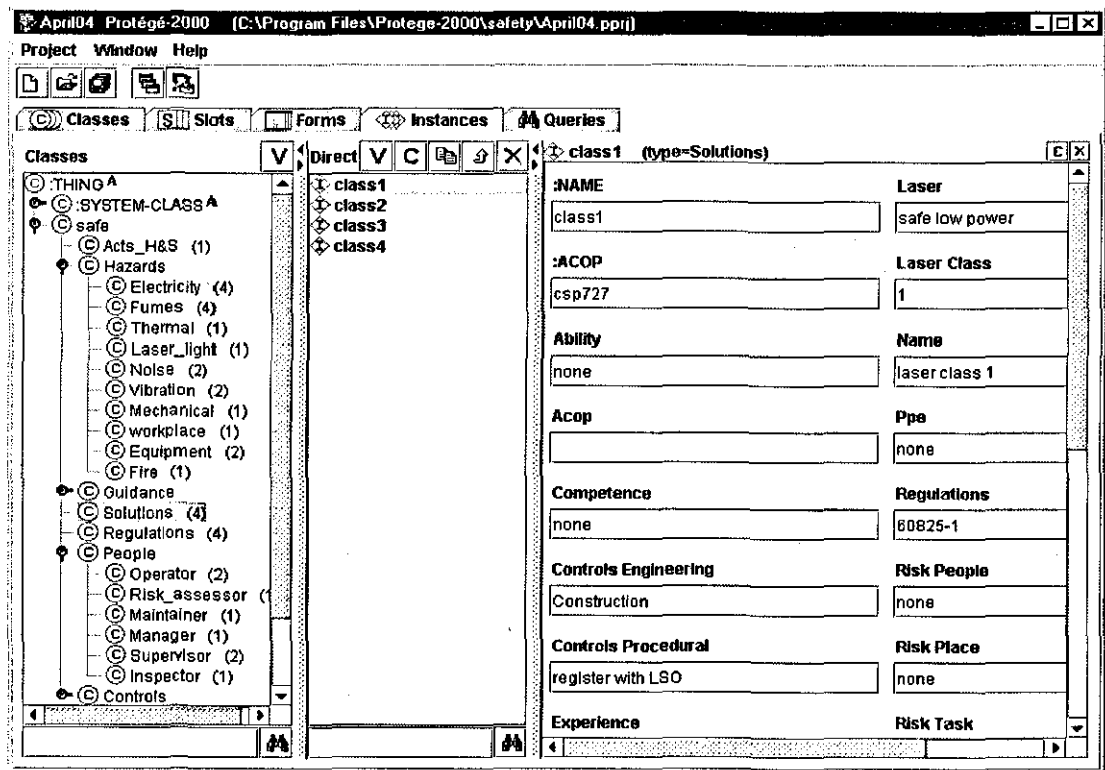


Figure 6.8 shows the choice of class (at the bottom) in which a query can be run, with the index of results on the right-hand side. The figure 6.9 shows the detail contained within a result. The queries can be developed and saved so that a common question can be listed in the query library or frequently asked questions to support other users.

Figure 6.8 Queries can be run on the data held by the software.

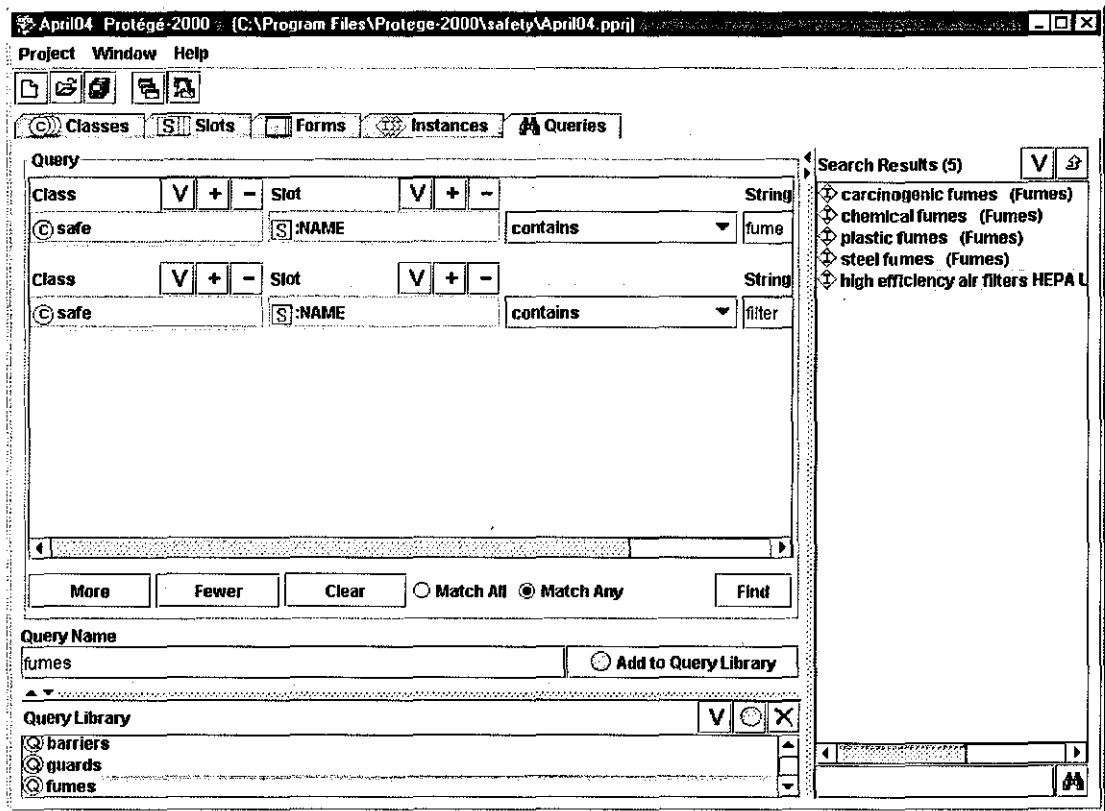
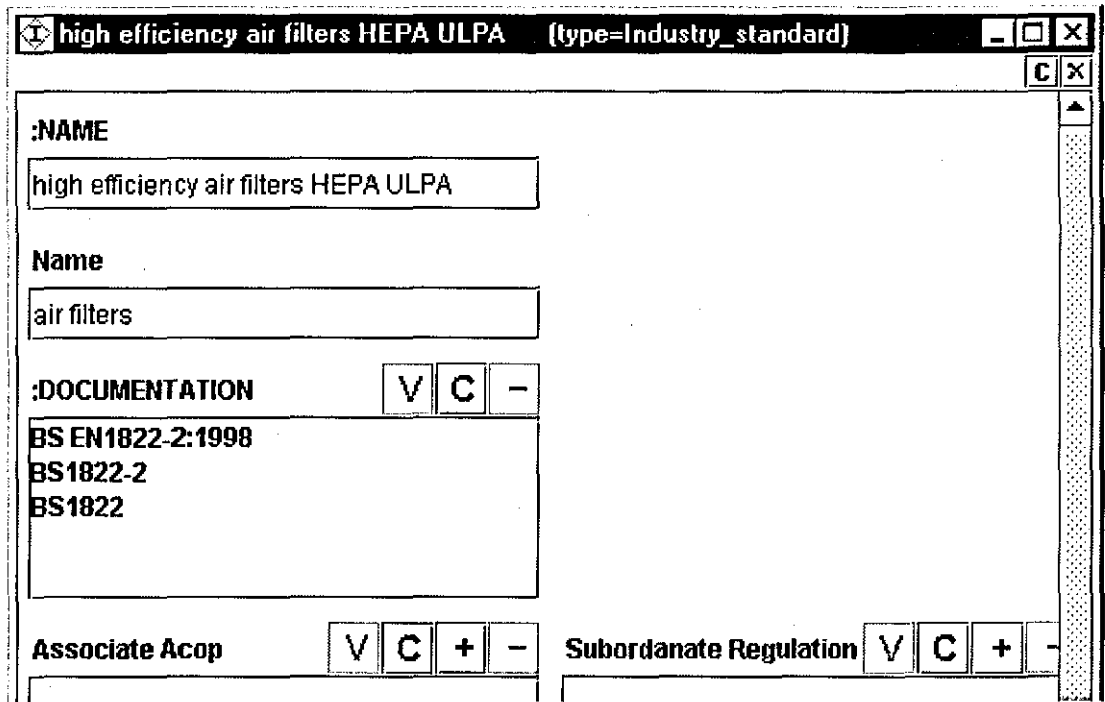


Figure 6.9 Example of a query related to fumes and can provide links to standards



6.2.5 Comparison of two trial ontologies.

Once initial working models had been developed using both Kaon and Protégé software packages they were compared to establish which should be fully developed and trialled.

Although the Kaon graphics allow several views of the information and visual linkages its support and examples were not as good as that provided for Protégé. During the development of both packages the advantages and benefits were considered. The findings were discussed with safety professionals and LSOs, who as potential users stated their preference as in table 6.2. If there had already been work completed to develop a base ontology model that could then be expanded the advantage of reduced development time was a strong plus point. However it also defined the base structure and relationship, which could be amended to address the particular case but would also require full knowledge or detail records of the previous structure to allow effective modifications to be made without undermining the model.

Table 6.2 Benefits and shortfalls of Kaon and Protégé software packages

Function	Kaon	Protégé	Preferred
Graphical display	Interactive model	Plain table	Kaon
Developed examples	Conceptual	Full working example	Protégé
Support tutorial	Some support	Several full presentations	Protégé
Cost of software	Freeware	Freeware	Both
Discussion groups for support	Few	Many across the world	Protégé
Speed, memory requirements	Standard PC	Standard PC	Both
Ease to understand concept and application to real world	Could see linkages but not achieve text output	Could get plain text answers and diagrammatic outputs	Protégé

The preferred software for the exemplar was Protégé (174) that was developed to a working model and trailed. This was because it has good general support, several

working examples are available (Newspapers and wine) and a good web site with frequently asked questions (FAQ) to support development. This gave confidence that a successful exemplar could be produced to support the trial and any future development.

6.3 Exemplar ontology development and trials.

From these trials a general safety ontology has been developed, which has been expanded to cover hazards from machinery including lasers. An example of the coding linkage is shown in chapter 9.2 where part of the safety coding has been listed

The concept of classes was developed from the 5 steps to risk assessment structure with the examples of hazards and solutions from Internet sources such as RLI and BS EN standards (4 21). The interrelationship between classes was added once the framework had been developed. The model has been developed with direct input as the automatic linkages across different software bases are still being developed. This has been proved in some cases but general packaging of code and transmission across the web has required additional support to develop the protocols (175). Protégé had been updated to version 3 with the Beta version available from June 2004, then to version 3.2 in 2005, the graphical displays have been improved but the translation between software protocols has not been fully developed at present.

The Protégé example has been trialled by a group of over 50 people including operators, safety professionals and laser specialists. The trial compared the quality of information and how long it took to identify answers. The questions address several industrial hazards as well as the specific laser hazards in a number of situations.

One large group of people involved with the trial was confirmed as having also no previous knowledge of the laser standards or specific hazards. The trials were conducted by providing access to either books, the Internet or the Protégé exemplar ontology example. Timing of the monitored trials, measured in minutes, was of how long it took them to achieve an answer with which they were satisfied. The time taken has been averaged over the groups to the nearest minute entered in the table below. The results were also graded for the quality of the results on a scale of 1 to 5 with 5 being the best, a

solution that could be applied. The criteria for quality were scored on identification of hazards, who maybe harmed and solutions with examples of application.

Three questions used were related to :-

1. Laser class and control systems.

Question:- What controls are required for a class 3 laser?

2. Control of fumes & health hazards.

Question:- What controls are required for laser processing?

3. Barriers & guards.

Question:- Guidance or solution of barrier or guards to be used for class 4?

These questions were developed from those posted on FAQ on laser safety Internet sites (69) and were reviewed by experienced laser safety officers. These questions were chosen as representative of the typical level asked by people new to lasers or when an existing laser is replaced or significantly modified.

Table 6.3 Results of searches of information sources

Time - minutes Quality – 1 low 3 good 5 best		Books Time Quality		Internet Time Quality		Ontology Time Quality	
1.	What controls are required for a class 3 laser?	20	1	10	3	5	5
2.	What controls are required for laser processing?	15	1	12	2	3	4
3.	Guidance or solution of barrier or guards to be used for class 4?	17	1	14	3	4	5
Rounded average score for all questions (actual score)		17 (17.3)	1 (1)	12 (12)	3 (2.67)	4 (4)	5 (4.67)

The results in Table 6.3 clearly show (only 4 minutes rather than 17 and a higher quality of 5 rather than 1) that a structured safety ontology can provide superior results in a shorter time than other methods of searching the Internet for solutions. Laser safety officers confirmed the exemplar provided a wider range of hazards, controls and solutions than other sources.

The results from this trial show a higher quality of results in a shorter time by using the ontology rather than the Internet alone and both are superior to textbooks. The quality of answers from books related to the date of publication. However they often lacked clear detail of the standard or action required. The World Wide Web had a few excellent examples but the user knowledge/ability to refine answers and use effective search terms made a large difference in the speed and quality of results. The ontology route provided a clear answer with supporting links to legislation that could be used to identify a specific standard or a proven solution.

Participants in the trial were also asked if they would use the exemplar software system in the future.

Table 6.4 Number of people who would or would not use the trial software (N=50)

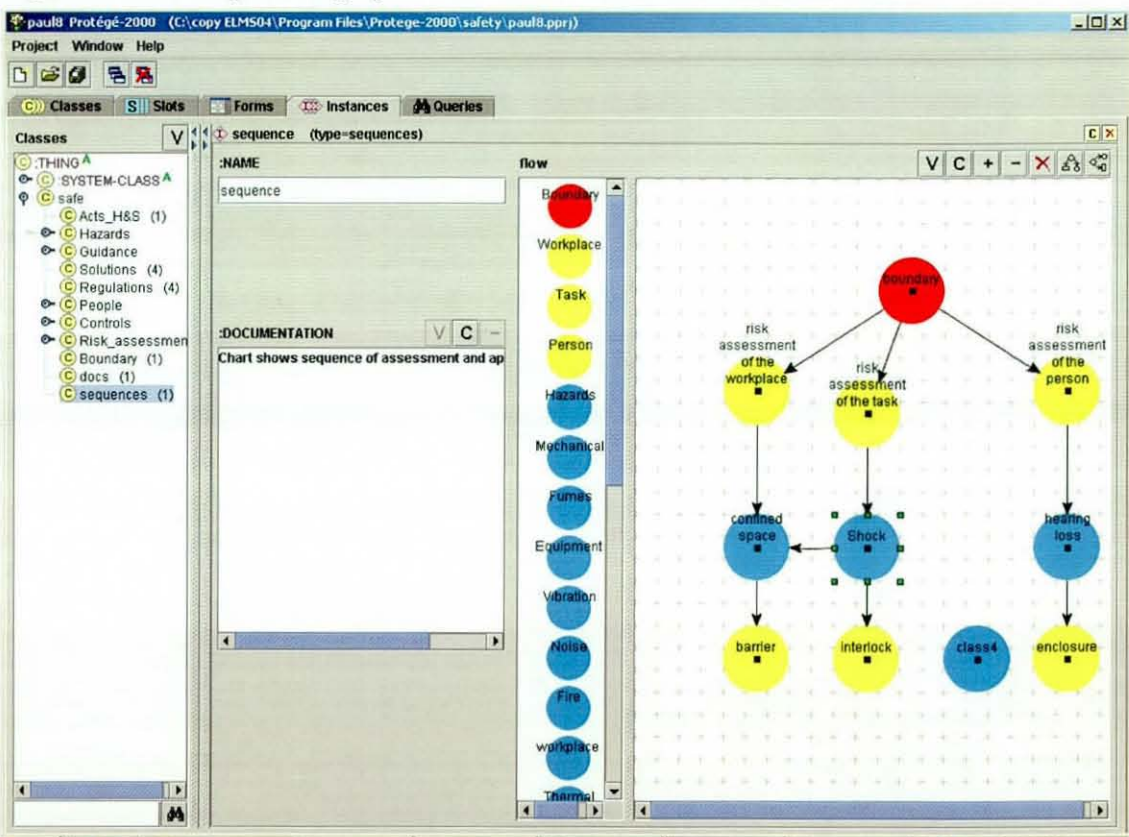
	Safety staff	Laser staff	Total
Would use the exemplar and found it useful	17	15	32
Would use the exemplar	6	3	9
Would not use the exemplar but ask a LSO	7	2	9
Total	30	20	

The figures of 9 “would not use” compared with 9 plus 32 that “would” gives a ratio of $41/50=82\%$

Substantially more staff would use the software as it was quicker and would give up to date information. The figure of 82% exceeded the target of 80% of the applications as quoted by TI indexes. (142)

There was a strong confirmation that text output was still preferred, although some additional development was undertaken to construct a trial graphical section. This graphic tool is still limited in layout and function but is to be improved in future upgrades of Protégé. The figure 6.10 below shows a screen shot of the standard tabs window with a graphic of risk assessment and hazards. This can be used to access text outputs but requires independent development rather than being self-generating at present.

Figure 6.10 Example of a graphic of risk assessment and hazards.



A consideration of the trial system is the quality of the results and if they are retrieved from trusted sites. The range of sites can be set in the preferences section of the web browsing tool, however restrictions should be balanced against the range of sites that could provide detail specific solutions. During the development of the exemplar the accuracy of the information retrieved was assessed to guide restrictions of access to preferred sites.

6.4 Summary

The original trial CD was identified as having shortfalls, which could be addressed by accessing the information on the World Wide Web, however access and interpretation required development. The benefits of the software search tool are it is quicker, gives better and more specific information and safety solutions to address laser and other safety hazards. A structured search tool, to use a web robot, was designed to bring specific solutions to address the hazards. When searching the World Wide Web it requires the sense of the words to be linked to obtain superior results. This led to the construction of a dedicated ontology and search process being undertaken and showed a reduction by a factor of 4 in comparison with only using books to the time taken to achieve useful results that were also of a better quality.

The structure developed was based on a risk assessment and solutions basis so that future enhancement could build on the fundamental foundation of risk assessing and controlling hazards. The development and trials were aimed at laser safety linked to general safety hazards associated with lasers, to bridge the gap between the two approaches. The taxonomy developed included the people, equipment and arenas in which lasers are used, each of which can be the focal search point. The trial showed significant improvement in quality and speed of obtaining accurate results and was confirmed as a preferred route to search for laser safety information.

The ontology exemplar can be extended to support the wider aspects of safety and cover the specific of the safety aspects of lasers. There is a wider market of general safety that will be interested in the ontology for safety. This shows that an ontology structured search with a web robot can provide safety solutions to hazards and problems that are specific and up to date.

7. DISCUSSION

As stated before – safety requirements are known but not communicated or applied. The HSE are building on this communication incentive to invigorate the 'Safety is good business' message to employers. The list of incidents and the safety systems, training and culture, would allow incidents to be avoided if the knowledge were applied. The knowledge of how to make laser use safer should be promulgated. This was the driving issue for this research and informatics trial.

In the literature review it was confirmed that the laser safety standards are focused around biological limits viewed from an optical hazard perspective. There is a poor linkage to general safety hazards associated with a laser. This position has continued for many years throughout the world. The slow pace of change of legislation and that the standards have only identify the safety limits rather than the solutions, has not helped the application of proven solutions in the workplace.

The survey conducted as part of this thesis was extended to more laser sectors. However similar results to previous surveys in the 1990's which confirmed that in general, laser safety issues and the support remain at the same level. A few specialist high hazard industries are making the link due to other deliverables such as safety cases.

Solutions and safety information are available but not easy to find. Books and publications have information but not often in one place or with the examples of application of solutions.

Electronic formats are easier to search but are famine or feast, either providing too much or too little information. A bespoke CD was identified as a possible solution. It can be supplied with a laser, so is available at the point of use, but it is fixed in time. The Internet has universal access but there is so much information the difficulty is to find a relevant part and at the detail required.

A trial CD was produced that had information at three levels to meet most laser safety requirements in a sector but it is fixed in time. The search ability is good but limited to what is on the CD. The mix of laser and general safety provided is a step forward but still does not meet all of the user requirements. Although the CD was developed from a general safety perspective it still was limited to the specific cases. It did not bring the ability to search outside particular applications or more general safety information. Information is not the limiting factor. Easier and broader access is required. The CD reduced the time taken to answer a question but was still, on this example, only from a laser perspective and not covering the general case. It unfortunately enhances the belief that a CD improves the answer, but it is only quicker access to view the original issues and information.

The aim to improve the search tool was to sift the available knowledge to gain the relevant part more quickly. The target of achieving 80% of the information required was met with the ontology search system. A structured search tool using an ontology was identified as a better solution. Information is put onto the World Wide Web by a wide range of people and from a wide range of sources. An improved search function to find the result you need is the key: to get the information that is relevant when you search on "laser safety" so you do not just get "goggles" but how to improve safety and applicable solutions. The structure search lists can give improved results but still not the refined results.

The ontology uses the sense of the word so returns superior results. Several software programs were trialled to develop the ontology. Those trialled had different benefits, such as graphical views or plain text results. Selection by features, such as support and examples, allow a working exemplar to be developed. The trial of building an ontology to allow the required scope and structure to be established. The development of the ontology was focused on being able to deliver appropriate timely results.

The trialled ontology gave faster (4 minutes rather than 17) and more accurate results (appropriate and compliant with the safety requirements) when searching for safety information on lasers than using reference books. When applied to a laser system the aspects of human factors must be included when planning/managing work, to make it

easy to comply with engineering controls and interlocks, make the task ergonomic and design the equipment as a whole. A holistic approach to the task and equipment will produce more effective solutions and efficient processes. (122)

Rather than just considering the radiation hazard or just the engineering hazards, which will not address all of the issues, it is better to consider safety of all of the task and equipment to produce an embracing solution that will keep people and equipment safe. These should be included in the ontology thereby highlighting the hazards, which might otherwise be missed/ not considered.

8. Conclusions.

The survey of application in the industrial areas that had been undertaken in 1993 and 1995 were extended in this thesis to other areas, such as medical and military. These sectors and the control in these organisations gave different responses, when compared with a jobbing metal cutting workshop of the original survey.

Research identified that the laser safety standards are not applied or understood and lack easily accessible, practical examples. Understanding of the laser standards has made little progress when compared with other safety changes, such as the implementation of the CDM regulations. (46) During research vast resources of written and electronic information were identified, but many of the World Wide Web sources have only been available in the last few years. This is indicative of a change in the way information is now gathered and broadcast.

8.1 Relational search engines

The issue was to re-map the problem into a new information base starting with realisation that the wrong data set and the wrong viewpoint were used. A revised training and information program can promulgate this idea, showing the broader picture to develop the perception of the individual. This could then use one of the new relational search engines to improve overall performance by identifying specific solutions to address their hazards.

Developments in relational search engines and web robots provide the opportunity to data mine information specific to the issue and are constantly updateable. Specific information that is in the correct context and at a level the user can comprehend is being provided in certain topics. There are ontologies being developed that allow wider and related knowledge to be sifted, from excellent sources, that would otherwise remain untapped. Accurate solutions, to eliminate or reduce the risk of a hazard causing harm, are available to be included in design or retrofit for existing systems. A wider knowledge base will provide a superior solution, provided the collection and sift is appropriate to

the domain or topic being considered. Development of safety ontologies will provide that access to the information, knowledge and wisdom that have been put on the World Wide Web.

8.2 Implementation.

To get the message about laser safety through will require the established safety practitioners to support the laser safety community to take a new look at the way safety is applied to lasers. Laser safety needs to be seen as a part of general safety and will be if all the hazards, including radiation, are promulgated and included as 'business as usual'.

Information is available via the World Wide Web but making it easier to find/access, by providing an ontology framework that will search for knowledge, will encourage the user to look at the present process and apply a solution that is good for safety and so good for business. Search engines are being developed that can search more deeply and specifically on the Internet. This allows more relevant information to be obtained but does require some initial development of the correct search terms. When the search structure is developed it will drive the review from a general safety perspective and include laser hazards such as radiation. This will give users and manufacturers far better support than is readily available at present.

The information from accidents is known but not applied. The access to information of solutions is not easy to access so is not followed. Improved access to information and solutions will increase the application of suitable control measures to the use of lasers. Good laser safety is difficult to achieve within a poor safety culture. The reason why there is a poor safety culture must be addressed. Incidents are due to lack of knowledge or deliberate acts and the lessons learned should be fed back to improve systems and controls.

8.3 Further work.

- A harmonised approach to laser safety.

Rather than continue to patch up a failing standard, a complete fresh approach is required. This should be authored in conjunction with the general regulatory framework. This would include harmonisation with other standards that address interlock and guarding requirements as well as bridging the gap between beam and non-beam hazards.

- Safety ontology.

The trial ontology search listing should be extended to complete the exemplar to make a fully working model for laser safety. This can be in one sector and then expanded, once it is running, to support other sectors. Support from the laser experts to record hazards and working solutions, which can share the learning in the community, would underpin the linkage for the search.

The specific laser safety ontology can be refined to update the search linkages for a wider range of laser safety hazards specific to the manufacturing sector. The layout of the output text forms can be adapted to match a number of industry safety system formats, that will allow a wider trial base to utilise the software directly in work scenarios. The learning from these additional trials will identify the stronger common linkages and the bespoke sector variations that should be developed to allow the software to be used more effectively in other sectors.

The improved range of solutions to hazards can be adapted to improve application and future designs. The use of this technique to search will allow the development of bespoke solutions as well as increase the possible adaptations of concepts to areas not previously realised because of the greater linkage.

If a group of connections within the ontology are amended, then the focus of the search can be moved to a particular process or specific hazard. This is the way forward to provide clear perception of hazards and the appropriate control mechanisms. The safety ontology can be expanded to address other areas of safety by amending the search

criteria and linkage. The base model of identifying hazards and control measure combined with who is involved to select the hierarchy of control measures is common to all areas of safety. This has the potential to address a huge range and number of hazardous situations that would enable appropriate solutions to be identified and applied quickly in a cost-effective manner.

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9.2 Support information. Example of coding for an ontology for safety.

Example of coding for Safety ontology

```
; Tue Apr 20 20:53:55 BST 2004
;+ (version "1.9")
;+ (build "Build 1120")

([access] of Access)
([ACOP+5+steps+to+risk+assessment] of ACOP
  (%3ADOCUMENTATION
    "INDG163 (REV1) "
    "0717615650")
  (name "5 steps to risk assessment"))
([acop+confined+space] of ACOP
  (%3ADOCUMENTATION
    "L101"
    "0717614050")
  (name "confined space")
  (regulations "confined spaces regulation"))
([ACOP+PUWER+regulations] of ACOP
  (%3ADOCUMENTATION "0717616266")
  (associate+acop
[high+efficiency+air+filters+HEPA+ULPA]))
  (name "ACOP PUWER regulations")
  (regulations "L22"))
([barrier] of Barrier
  (%3ADOCUMENTATION
    "EN953"
    "EN12626"
    "EN292"))
([boundary] of Boundary
  (%3ADOCUMENTATION "enclosure")
  (seq-chart
    [risk+assessment+of+the+workplace]
    [risk+assessment+of+the+task]
    [risk+assessment+of+the+person]))
([carcinogenic+fumes] of Fumes
  (damage "body tissue")
  (%3ADOCUMENTATION
    "HSG193"
    "0717624218"
    "Control of substances hazardous to health")
  (health "harmful")
  (harm "cancerous")
  (injury "person"))
([CHART] of docs
  (docs_chart
    [safety+of+laser+products+60825]
    [Health+%26+Safety+at+Work+Act+1974+etc]
    [safety+of+machinery+design+EN292]
    [ACOP+PUWER+regulations]
    [safety+signs+and+colours+BS5378+part+1+1980])
```

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        [safety+of+machinery+EN12626]
        [high+efficiency+air+filters+HEPA+ULPA]))
([chemical+fumes] of Fumes
  (damage "equipment")
  (%3ADOCUMENTATION
    "COSHH"
    "HSG193"
    "INDG136")
  (health "hazard")
  (harm "people")
  (injury "respiratory"))
([class1] of Solutions
  (%3ADOCUMENTATION "60825")
  (competence "none")
  (risk_people "none")
  (training "awareness")
  (supervisor_competence "registration required")
  (controls_engineering "Construction")
  (laser_class "1")
  (experience "none")
  (%3AACOP "csp727")
  (ability "none")
  (guidance "www.tuwien.ac.is")
  (name "laser class 1")
  (health "no direct issues")
  (laser "safe low power")
  (regulations "60825-1")
  (risk_place "none")
  (controls_procedural "register with LSO")
  (risk_task "none")
  (ppe "none"))
([class2] of Solutions
  (%3ADOCUMENTATION "60825")
  (competence "awareness")
  (risk_people "low")
  (training "awareness")
  (supervisor_competence "registration required")
  (controls_engineering "must be visible wavelength")
  (laser_class "2")
  (experience "none")
  (%3AACOP "csp727")
  (ability "none")
  (guidance "csp727")
  (name "laser class 2")
  (health "none")
  (laser "low power")
  (regulations "60825-1")
  (risk_place "low")
  (controls_procedural "register with LSO")
  (knowledge "hazards")
  (risk_task "low"))
([class3] of Solutions
  (%3ADOCUMENTATION
    "class3r"

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        "60825")
    (competence "Laser user")
    (risk_people "medium")
    (training "training to lso")
    (supervisor_competence "competency required")
    (controls_engineering "barriers or containment")
    (laser_class "3")
    (experience "training to use equipment")
    (%3AACOP "csp727")
    (ability "laser knowledge")
    (guidance "csp727")
    (name "laser class 3")
    (health "eye hazard")
    (laser "medium power")
    (regulations "60825-1")
    (risk_place "low")
    (controls_procedural "operating procedures")
    (knowledge "hazards and controls")
    (risk_task "medium")
    (ppe "to be assessed"))
([class4] of Solutions
    (%3ADOCUMENTATION "60825")
    (competence "laser safety officer")
    (risk_people "incorrect action")
    (training "safety awareness")
    (supervisor_competence "skilled to supervise")
    (controls_engineering "enclosure")
    (laser_class "4")
    (acop "code to the regulations")
    (experience "3 years using lasers")
    (%3AACOP "60825-2")
    (ability "meet operation requirements")
    (guidance "CSP 725")
    (name "person item name")
    (health "eye and skin")
    (laser "high power specific laser knowledge")
    (regulations "BS EN 60825")
    (risk_place "Indoor")
    (controls_procedural "written procedure")
    (knowledge "know the principle of equipment")
    (risk_task "class 4 laser use")
    (ppe "protective equipment assessment"))
([competent+risk+assessor] of Risk_assessor
    (%3ADOCUMENTATION "competent risk assessor"))
([confined+space] of workplace
    (%3ADOCUMENTATION
        "INDG258"
        "management of health and safety regulations
1999"
        "confined spaces regulation 1997")
    (seq-chart [barrier])
    (harm "people")
    (injury "asphyxiation"))
([electrostatic] of Electricity

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```

    (damage "electronic equipment")
    (%3ADOCUMENTATION "electricity at work regulations")
    (harm "people")
    (burn "possible")
    (injury "knock on can be significant")
    (strength "voltage dependent")
    (shock "minor"))
([EMC] of Electricity
    (damage "equipment electronic")
    (%3ADOCUMENTATION "electro magnetic compatibility")
    (harm "control systems")
    (burn "possible")
    (injury "burn")
    (strength "medium")
    (shock "possible"))
([enclosure] of Enclosure
    (%3ADOCUMENTATION
        "EN953"
        "guards"))
([Eye+hazard] of Laser_light
    (damage "eye")
    (harm "loss of sight")
    (injury "burn"))
([fire] of Fire
    (damage "equipment")
    (%3ADOCUMENTATION
        "The fire precautions (workplace) regulations
1999"
        "The fire precautions act 1971"
        "management of health and safety 1992")
    (harm "people")
    (injury "people"))
([guard+ineffective] of Equipment
    (damage "equipment")
    (%3ADOCUMENTATION
        "EN953"
        "safety of machinery"
        "guard"
        "IEC60204-1")
    (harm "people")
    (injury "severe"))
([guard+missing] of Equipment
    (damage "operation")
    (%3ADOCUMENTATION
        "EN953"
        "safety of machinery"
        "IEC60204-1"
        "guard")
    (harm "people")
    (injury "severe"))
([Health+%26+Safety+at+Work+Act+1974+etc] of Acts_H%26S
    (H%26S+at+work+Act "1974")
    (subordinate+regulation
        [safety+of+machinery+design+EN292]

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[safety+of+machinery+EN12626]
[safety+of+laser+products+60825]))
([hearing+loss] of Noise
  (damage "ears")
  (%3ADOCUMENTATION "physical agents directive")
  (seq-chart [enclosure])
  (harm "loss of hearing")
  (injury "broken ear drum"))
([high+efficiency+air+filters+HEPA+ULPA] of
Industry_standard
  (%3ADOCUMENTATION
    "BS EN1822-2:1998"
    "BS1822-2"
    "BS1822")
  (name "air filters"))
([industry+standard] of Industry_standard
  (%3ADOCUMENTATION "BCGA")
  (name "British compressed gas association"))
([inspector+workshops] of Inspector)
([interlock] of Interlock
  (%3ADOCUMENTATION "EN60204 interlock specification"))
([laser+safety+officer+1] of Training
  (%3ADOCUMENTATION "laser safety officer 1 training
course")
  (competence "laser safety officer 1")
  (skills "risk assess laser safety"))
([machine+shop+supervisor] of Supervisor
  (%3ADOCUMENTATION "PUWER")
  (skills "machining operations")
  (name "Peter Jones")
  (experience "apprenticeship and 2 year experience")
  (role_title "machine shop supervisor"))
([machinist+lathe] of Operator
  (competence "machinist")
  (name "Joe Smith")
  (knowledge "apprenticeship")
  (role_title "Lathe turner"))
([machinist+miller] of Operator
  (competence "machinist")
  (name "Fred Jones")
  (knowledge "C&G craft tradesman")
  (role_title "miller"))
([maintainer+workshops] of Maintainer)
([mechanical] of Mechanical
  (damage "equipmnet")
  (%3ADOCUMENTATION "PUWER L22")
  (harm "puncture break")
  (injury "person"))
([noise+loss+communication] of Noise
  (damage "equipment")
  (harm "person")
  (injury "person"))
([Permit+to+work] of Permit_to_work)
([plastic+fumes] of Fumes

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(damage "people")
(%3ADOCUMENTATION
  "ACOP L5"
  "COSHH LEV")
(health "hazard")
(harm "severe")
(injury "respiratory"))
([plating+shop] of Supervisor
  (skills "plating operations")
  (name "Joe Brown")
  (experience "apprenticeship and 3 years")
  (role_title "plating shop supervisor"))
([PUWER+1998] of Regulations
  (%3ADOCUMENTATION "L22"))
([risk+assessment+of+the+person] of Person
  (%3ADOCUMENTATION "SQEP")
  (seq-chart [hearing+loss]))
([risk+assessment+of+the+task] of Task
  (%3ADOCUMENTATION "task")
  (seq-chart [Shock]))
([risk+assessment+of+the+workplace] of Workplace
  (%3ADOCUMENTATION "workplace")
  (seq-chart [confined+space]))
([safety+of+laser+products+60825] of Regulations
  (%3ADOCUMENTATION "60825")
  (associated+industry+std
    [ACOP+PUWER+regulations]
    [safety+of+machinery+EN12626]))
([safety+of+machinery+design+and+construction] of
Industry_standard
  (%3ADOCUMENTATION
    "BS EN1034:2000"
    "BS1034")
  (name "paper making and finishing"))
([safety+of+machinery+design+EN292] of Regulations
  (%3ADOCUMENTATION "EN292")
  (associated+industry+std
    [safety+of+laser+products+60825]
    [safety+of+machinery+EN12626]))
([safety+of+machinery+EN12626] of Regulations
  (%3ADOCUMENTATION "EN12626")
  (associated+industry+std
    [safety+signs+and+colours+BS5378+part+1+1980]))
([safety+signs+and+colours+BS5378+part+1+1980] of
Industry_standard
  (%3ADOCUMENTATION
    "BS5378 part 1 1980"
    "BS5378 part 1"
    "BS5378")
  (name "safety signs and colours"))
([Safety1_00030] of %3APAL-CONSTRAINT)
([Safety2_00058] of %3APAL-CONSTRAINT)
([Safety2_00059] of %3APAL-CONSTRAINT)
([Safety2_00062] of %3APAL-CONSTRAINT)

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([Safety3_00091] of %3APAL-CONSTRAINT
  (%3APAL-NAME "Lathe")
  (%3APAL-DESCRIPTION "Machine tool in workshop"))
([Safety3_00093] of %3APAL-CONSTRAINT
  (%3APAL-STATEMENT "x")
  (%3APAL-NAME "Lathe Colchester")
  (%3APAL-DESCRIPTION "z")
  (%3APAL-RANGE "w"))
([Safety3_00103] of %3APAL-CONSTRAINT
  (%3APAL-NAME "referrer"))
([sequence] of sequences
  (%3ADOCUMENTATION "Chart shows sequence of assessment
and applying control")
  (seq-chart
    [boundary]
    [risk+assessment+of+the+workplace]
    [risk+assessment+of+the+task]
    [risk+assessment+of+the+person]
    [Shock]
    [confined+space]
    [hearing+loss]
    [enclosure]
    [barrier]
    [interlock]
    [class4]))
([Shock] of Electricity
  (damage "possible equipment")
  (%3ADOCUMENTATION "electricity at work regulations")
  (seq-chart [interlock])
  (harm "people")
  (burn "skin")
  (injury "possible death")
  (strength "strong")
  (shock "230"))
([shop+manager] of Manager
  (name "Mark Prior")
  (responsibility "all operations in machine shop")
  (experience "apprenticeship and 5 years experience")
  (role_title "Machine shop manager"))
([short+circuit] of Electricity
  (damage "equipment")
  (%3ADOCUMENTATION "BS7671 IEE wiring regulations")
  (harm "people process")
  (burn "molten metal")
  (injury "burn")
  (strength "severe")
  (shock "likely"))
([skin+burn] of Thermal
  (damage "equipment")
  (harm "burn")
  (burn "skin")
  (injury "person"))
([Solutions] of %3ASTANDARD-CLASS
  (%3ASLOT-CONSTRAINTS

```

```
[Safety3_00091]
[Safety3_00093]))
([Sqep] of Assessment)
([steel+fumes] of Fumes
  (damage "people")
  (%3ADOCUMENTATION "LEV COSHH")
  (health "hazard")
  (harm "severe")
  (injury "respiratory"))
([vibration+equipment] of Vibration
  (damage "equipment")
  (%3ADOCUMENTATION "physical agents directive")
  (harm "people")
  (injury "possible"))
([vibration+person] of Vibration
  (damage "body tissue")
  (%3ADOCUMENTATION "physical agents directive")
  (harm "cell damage")
  (injury "white finger/hand/arm vibration"))
```

9.3 Companies and organisations surveyed.

This appendix has details of some of the companies surveyed that were reviewed in chapter 4. (Several required confidentiality regarding the information they provided)

Table 9.1 List of companies and people surveyed.

Company	Position of person	Process
1. NHS Basingstoke	Consultant	Ophthalmology
2. Kent University	LSO for campus	Research
3. Surrey University	LSO for campus	Research
4. Loughborough University	LSO for campus	Research
5. Laser Graphics	LSO for display	Entertainment
6. Hunting Bray	LSO for facility	Production, metal.
7. Oxford University	LSO for campus	Research
8. UKAEA	LSO for site	Research
9. Reading University	LSO for campus	Research
10. NHS Chester	LSO for hospital	Medical
11. Pfizers	LSO for company	Medical
12. Brush machines	LSO for company	Manufacturing
13. Ford motors	LSO for company	Manufacturing
14. Vauxhall motors	LSO for company	Manufacturing
15. Technical Indexes	Supervisor	Information systems
16. Railtrack	LSO for company	Manufacturing
17. USA Army	LSO for organisation	Military
18. JSP UK laser safety	LSO for organisation	Military
19. Hunting Bray	LSO for facility	Research
20. AWEML	LSO for facility	Research
21. Foster and Stewart	Supervisor for company	Veterinarian
22. Boundary Road	Supervisor for company	Dentist
23. 5750 Components Ltd	Supervisor	Manufacturing
24. Accrofab Ltd	Supervisor	Manufacturing

25. Allett Mower Ltd	Supervisor	Manufacturing
26. Atlas Dies	Supervisor	Manufacturing
27. Carlton Laser Services Ltd	Supervisor	Manufacturing
28. Oxford Lasers	Supervisor	Manufacturing
29. Cambridge Lasers	Supervisor	Manufacturing
30. John Marshall	Professor	Medical
31. Swansea NHS	LSO for site	Medical
32. Bath University	LSO for campus	Research
33. Ken Barat	LSO for NIF	Research

