RC-8
Laser Radiation Safety

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Abstract. The first time many organizations think about laser safety is either when the laser equipment arrives on site, when staff start asking questions or after an incident. This is not managing laser safety. A structured approach can be applied to any laser application to ensure that the risks are addressed. This approach consists of thinking about the life cycle of the laser product, the hazards presented by various components of the application, the control measures in place throughout the life cycle, and the people at risk.

1. Introduction

The first lasers were used in research and military environments, usually by the people who had developed them. However, in the early 1970s they moved from these well-controlled environments into shops where they were used as barcode scanners. The users were unlikely to fully understand the safety issues associated with the use of the laser and it was important for the manufacturers to take account of this.

Laser technology has continued to develop and lasers are now used in a very wide range of applications. Examples are presented in Table I.

Table I. Laser Applications

Category	**Applications**	
Medical	Diagnostic Procedures	Physiotherapy
	Surgery	Ophthalmology
	Dermatology	Dentistry
	Tumour Treatment	Patient Alignment
	Photodynamic Therapy	
Cosmetic	Hair Management	Refractive Surgery
	Tattoo Removal	
Manufacturing	Cutting	Surface Treatment
	Welding	Rapid Prototyping
	Drilling	Metrology
	Marking	Peening
Communication	Fibre Communications	Free-Space Communications
Entertainment	Laser Light Shows	Holography
Security	Holography, IR illumination	Scene of crime investigations
Construction	Alignment	Range Finding
Office	Laser Printers	Laser Pointers
	CD/DVD ROMS	
Retail	Barcode Scanners	
Domestic	CD/DVD Players	Novelty Products
Military	Range Finding	Target Designation
	Communications	Defence Weapons

For the employer who is new to laser technology the challenge can be to identify the risks from the laser application. Researchers, who may be involved with any of the applications outlined in Table I, often have the perception that any form of safety management will impede their ability to be creative.

Laser safety often focuses on the laser in isolation. However, this is only the starting point. As will be demonstrated, the same laser may be used for the same application in many different environments, and perhaps by different categories of people. The safety issues and the risks of injury may be completely different. The procedures outlined here will assist laser users by providing a methodical approach to the assessment.

2. Laser Safety Assessment Methodology

Any laser application can be broken down into a series of modules. The first is with respect to time: the so-called life cycle. Then the physical components of the laser application can be considered, along with the environment in which the product is used and who uses it. There are then the people at risk.

2.1 Life Cycle for a Laser Product

An organisation may acquire a laser after a range of decision processes. At the most basic, there may be a need to carry out a process that requires a specific laser radiation quality. The thought process from the initial idea through to operation of the product will be driven from the requirement to identify a product with the necessary laser characteristics. At the other extreme, a tool will be sought to undertake an operation, and the organisation has no need to know that a laser is involved in this operation at all. An example of this is the use of lasers in computer mass storage. The user is only interested in the ability to effectively store and retrieve information, not the characteristics of the laser device that may assist with this. Provided the manufacturer has considered the life cycle of the product, the people who may use it, the environment in which it is used and the people at risk, and addressed appropriate control measures to ensure that people are not at risk, there should be few residual safety issues.

The life cycle for a laser product can be considered from the perspective of a manufacturer of a product who is targeting a perceived, but perhaps uncertain, market; a user who knows what they want to achieve, but doesn't know at the outset how to achieve it; and a user who has a well identified need and is looking for a standard product. In all three cases, the life cycle tends to run as follows:

(a) Planning
(b) Design
(c) Manufacture
(d) Testing
(e) Transport
(f) Installation
(g) Commissioning
(h) Normal Operation
(i) Fault Conditions
(j) Maintenance
(k) Servicing
(l) Modification
(m) Decommissioning
(n) Disposal

The product manufacturer will be involved primarily with steps (a) to (d), but the actions taken at these early stages will have implications for all other parts of the life cycle. A developer-user may be involved with all stages of the life cycle, whereas a user looking for a standard product may only be involved from stages (f) to (n).

Feedback from the later stages of a life cycle is very important. For example, a laser product that requires routine user maintenance that is either time-consuming, costly, or presents a higher than acceptable risk of injury, may not be acceptable. Effective planning and design at stages (a) and (b) should have foreseen these problems. Pressure from users should ensure that the product is modified (stage (l)) or at least future developments take the issues into account.

Some of the stages of the life cycle are truly cyclic. For example, a typical laser product will loop between (h) and (j), hopefully avoiding stage (i). Servicing may take place periodically, resulting in a loop back to stage (g).

2.2 Laser Application Model

It is possible to divide any laser application into a number of components. Essentially, any laser application will consist of a laser, a beam delivery system and a process, ie what the laser beam does. All of this takes place in an environment, generally involving people. A schematic is shown in Fig. 1.

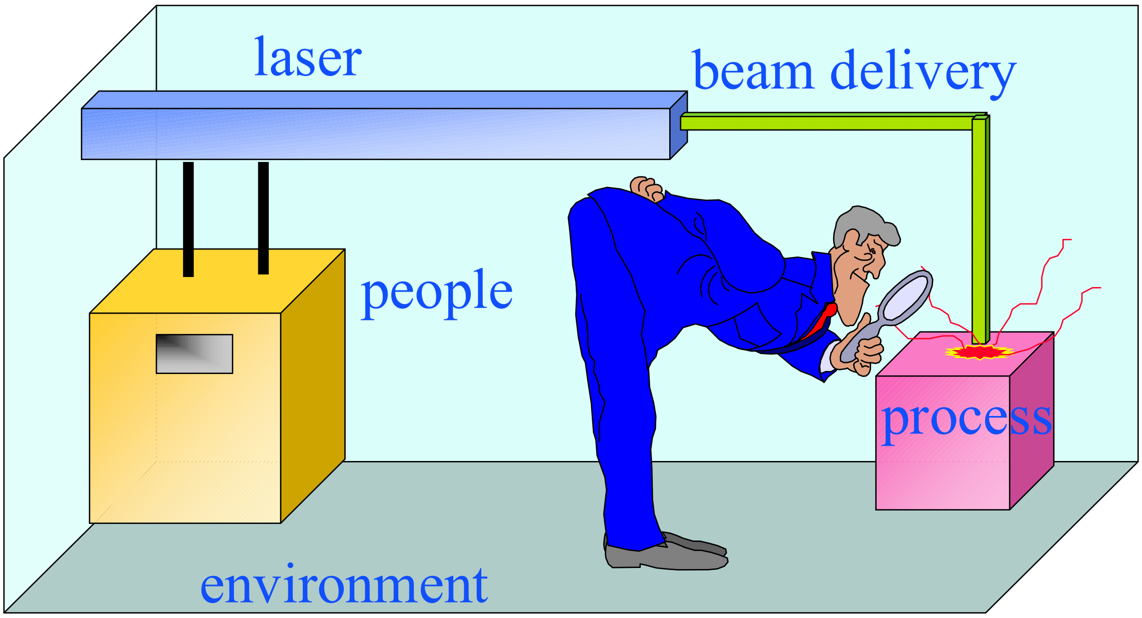

FIG. 1. Components of the Laser Application Model

A particular laser application may have more than one of some of the components. In particular, some laser applications have more than one laser, especially where one laser is used as the pumping source for another laser, and most laser applications have more than one beam delivery system.

The laser is defined here as being the device that emits the laser beam, taken from the output aperture of the laser device back through the device to the point where it connects to services. For example, the main electrical supply of a building will not generally be considered part of a laser, but a portable generator may be considered. There is a wide range of lasers available and each may have specific safety issues.

The beam delivery system may be transmission through the air, transmission through a fibre optic cable, through a beam tube or a combination of all three. There may also be a range of optical components, such as mirrors and lenses. All of these should be considered when identifying the hazards and should also include any support or manipulation systems. For example, there are specific safety issues associated with the use of robotically manipulated fibre delivery systems.

The laser process will usually be a combination of reflection, transmission or absorption of the beam and one of these processes may predominate. As a result of these processes, the target site may be altered. The safety issues from the process should include everything associated with the process, including the target material before, during and after receipt of the laser beam. For example, there may be issues associated with the handling of the target material and any laser induced gas or particulate products from the process.

After the laser process, there may be additional beam delivery systems. The beam may be scattered as a diffuse reflection or there may be specular (mirror-like) reflections. In many circumstances there will be a combination of the two. The beam paths should be analysed until the laser beam is absorbed or otherwise does not present a risk of injury or other adverse effects.

The laser application will be in an environment, and this may alter throughout the life cycle. Laser products such as laser printers and CD/DVD players may be in any environment but the "environment" considered here is constrained to the casing of the product, at least during normal reasonable use. Many industrial laser products are also constrained within an enclosure, but this may not be true during all parts of the life cycle. For example, if servicing operations require removal of panels and overriding interlocks then the environment may be the complete room in which the laser application is housed. If the application is outside then the environment may extend to large distances.

People can influence the safety of a laser product. These people may change throughout the life cycle. It would be reasonable to assume that the manufacturer will employ skilled staff, who may be trained to a higher level of laser safety awareness than the user. These engineers may also be responsible for undertaking servicing on customers' premises. When these operations are carried out, the engineers may employ local control measures, including laser safety eyewear. The engineers may be at risk of injury or death through their own actions, but other people could also be at risk. Another example is where the control for a laser product is remote to the point where a hazard, such as the laser beam, will be accessible. This may be true for laser communication systems. A person who initiates a transmission may put other people some distance away at risk of injury.

2.3 Identifying the Hazards

When considering the safety issues from a laser application it is tempting to focus on the laser beam. Whilst this may present a risk of injury, is in important to consider the other hazards, which may present more severe risks, including death.

The suggested approach to ensuring that all of the hazards are identified is to identify them for each of the compartments of the laser application model. It will then be appropriate to consider control measures that may be in place throughout the life cycle of the laser product. The analysis should include an assessment of likely fault conditions that could invalidate or compromise control measures.

A guide to identifying hazards can be to use a category checklist but care should be taken in case some hazards are outside the scope of the categories:

(1) Optical radiation, including the laser beam and collateral optical radiation
(2) Electricity
(3) Chemical or biological agents
(4) Mechanical hazards, including noise, vibration, mass, movement, etc
(5) Ergonomic hazards
(6) Temperature (high and low) and fire
(7) Ionising radiation from high voltage generators or laser process
(8) Electromagnetic interference with other equipment

Having identified the hazards and reviewed the control measures, it may be necessary to evaluate the risk from any potentially accessible hazards. There may be internationally accepted levels of exposure, or national regulations. There may also be aspects of exposure to the hazard that may be below levels likely to cause harm, but which may be annoying or distracting (such as noise). Depending on the environment, these may also need to be considered.

The International Commission on Non-Ionizing Radiation Protection has published guidance on exposure limits for laser radiation [1,2]. The beams from the laser application can be assessed against these values. However, laser products should also be classified against manufacturing standards[3] which provide an indication of the hazard level from the product under normal use. When assessing the laser product throughout its life cycle it is important to recognise that the classification may not provide an accurate indication of the accessible laser radiation.

2.4 Persons at Risk

The review of the life cycle for the laser application should also consider the people at risk. This process should include the type of person, ie trained, competent or a member of the public, and perhaps the number of people at risk. Obviously, at some stages of the life cycle, such as planning and design, there may be no one actually at risk. However, addressing issues at this stage can help to mitigate problems at other stages of the life cycle.

Categories of people at risk may include:

— engineers
— laser users
— other employees
— patients (if a medical laser)
— visitors
— public

It is usually found that particular groups of people are at risk from the hazards associated with specific components of the laser application at specific stages of the life cycle. A review of this data can identify where additional control measures may be required. The data can be expressed graphically as demonstrated in Fig. 2.

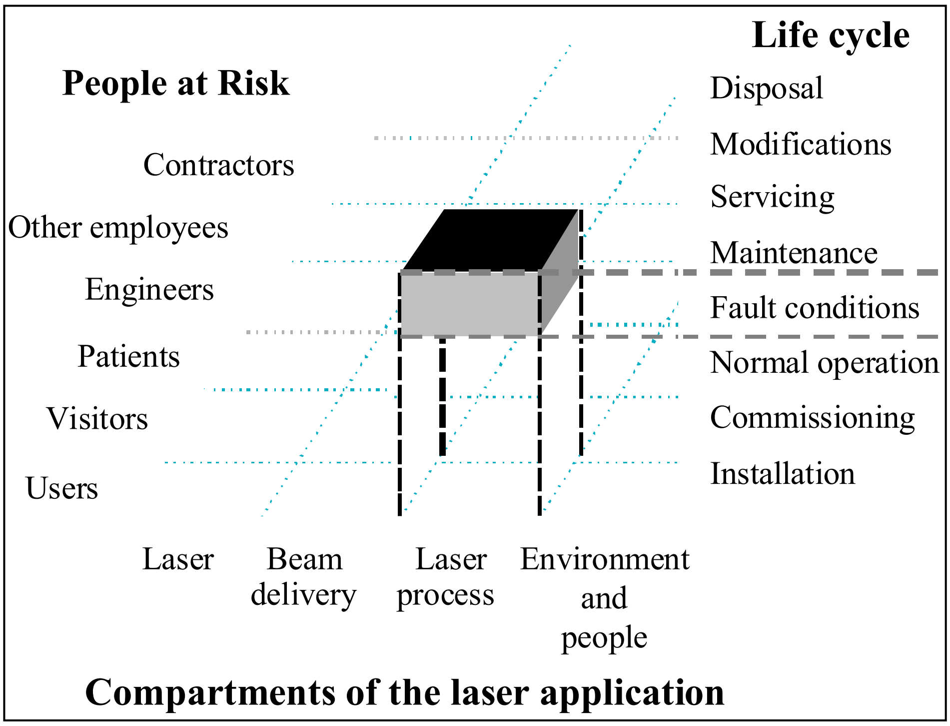

FIG. 2. People at Risk as a Function of Life Cycle and Laser Application Compartments

3. Transfer of Laser Products

A laser product or process may be developed for use in one environment or for use by people who are assumed to have a certain level of expertise or training. As laser technology has developed and, particularly, the unit cost of some laser devices has reduced, some laser products have transferred to environments or for use by people different from those originally foreseen by the product manufacturer. A specific example of this was the transfer of laser pointer technology from a relatively constrained professional presentation environment to public areas. Any assessment of the technology in its original environment would have shown that the risk of injury or other adverse incidents was very low. However, the same product shone into the eyes of someone driving a vehicle could have far-reaching consequences.

There are a number of other examples of laser technology moving from a professional market to a domestic market. These include laser alignment and distance measuring products originally used in the construction industry and now widely available for the home improvement market, and laser show technology being marketed for use on home entertainment systems. For such products it would be reasonable to expect the manufacturer to consider the life cycle of the product, with the potential assessment of additional safety issues from reasonably foreseeable misuse.

4. Control Measures

Most laser users are used to dealing with control measures for normal operation (stage (h) of the life cycle). These will include Standard Operating Procedures, training, signs, etc. There may be some consideration of alignment procedures (stages (g), (j) or (k)). The control measures appropriate for each stage of the life cycle need to be considered, taking account of the environment, people who may responsible for the same management of the process and the people at risk. The hierarchy of control measures should always be that engineering controls should be primary, followed by administrative controls. Only if these are not possible or effective should reliance be placed on personal protective equipment. In some laser applications, the appropriate control measures will be very environment or user dependent.

5. Conclusions

Laser technology is now used in a very wide range of applications. A methodology has been presented for assessing the safety issues from such technology for any application and environment. Such a systematic approach should ensure that appropriate control measures are specified and implemented.

6. References

1. International Commission on Non-Ionizing Radiation Protection. *Guidelines on Limits of Exposure to Laser Radiation of Wavelengths between 180 nm and 1 mm*, Health Physics, 71, 5: 804-819 (1996).
2. International Commission on Non-Ionizing Radiation Protection. *Revision of the Guidelines on Limits of Exposure to Laser radiation of wavelengths between 400nm and 1.4µm*, Health Physics, 79, 4: 431-440 (2000).
3. International Electrotechnical Commission. *Safety of Laser Products – Part 1: Equipment classification, requirements and user's guide*, IEC 60825-1, Edition 1.2, Geneva, (2001).

IRPA 11

International Radiation Protection Association
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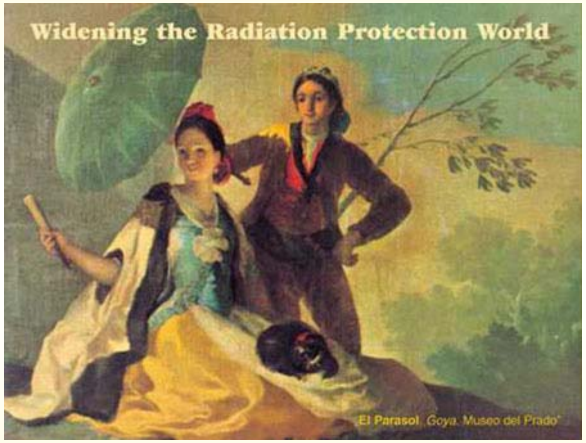
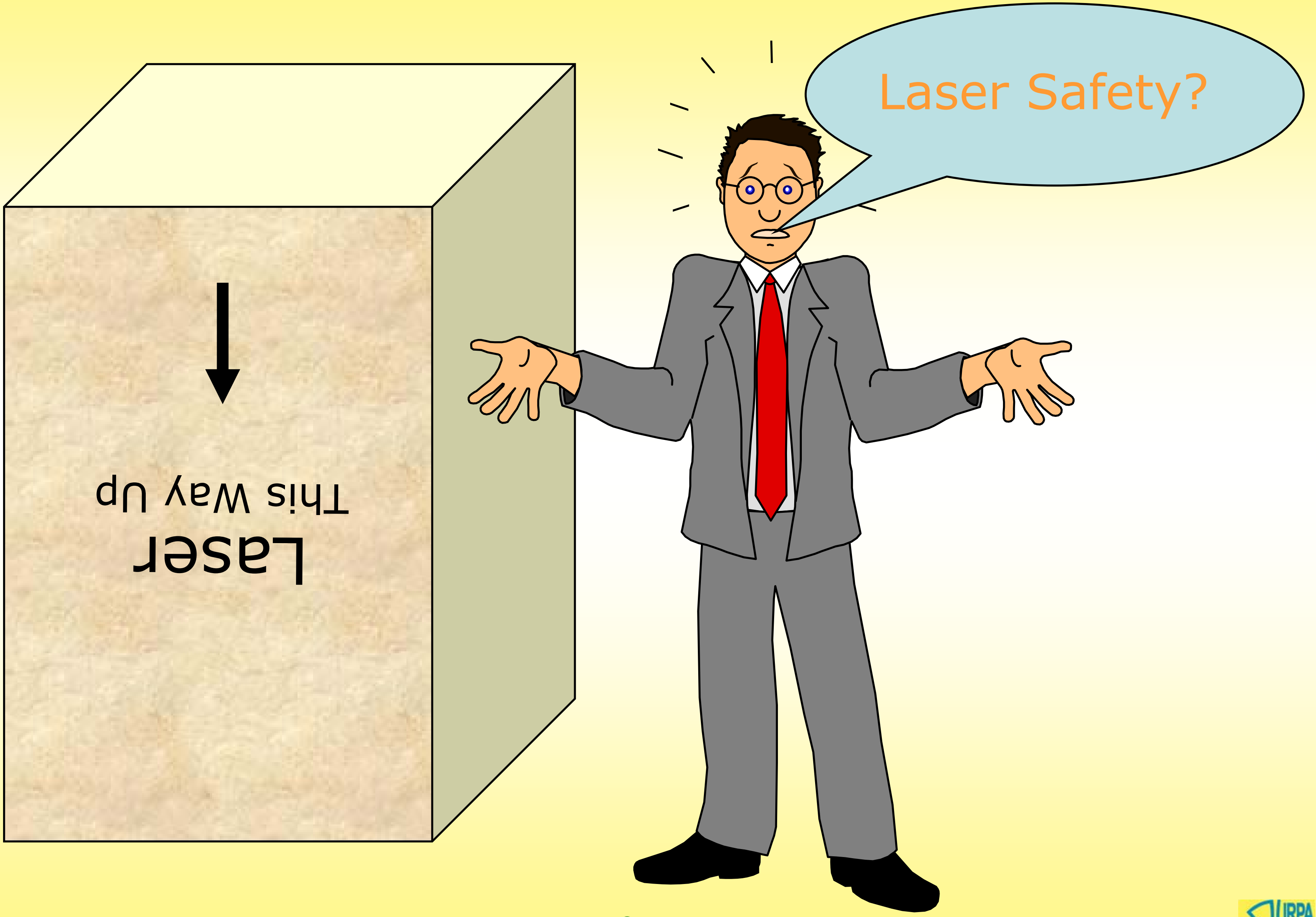
Madrid, Spain - May 23-28, 2004



Refresher Course

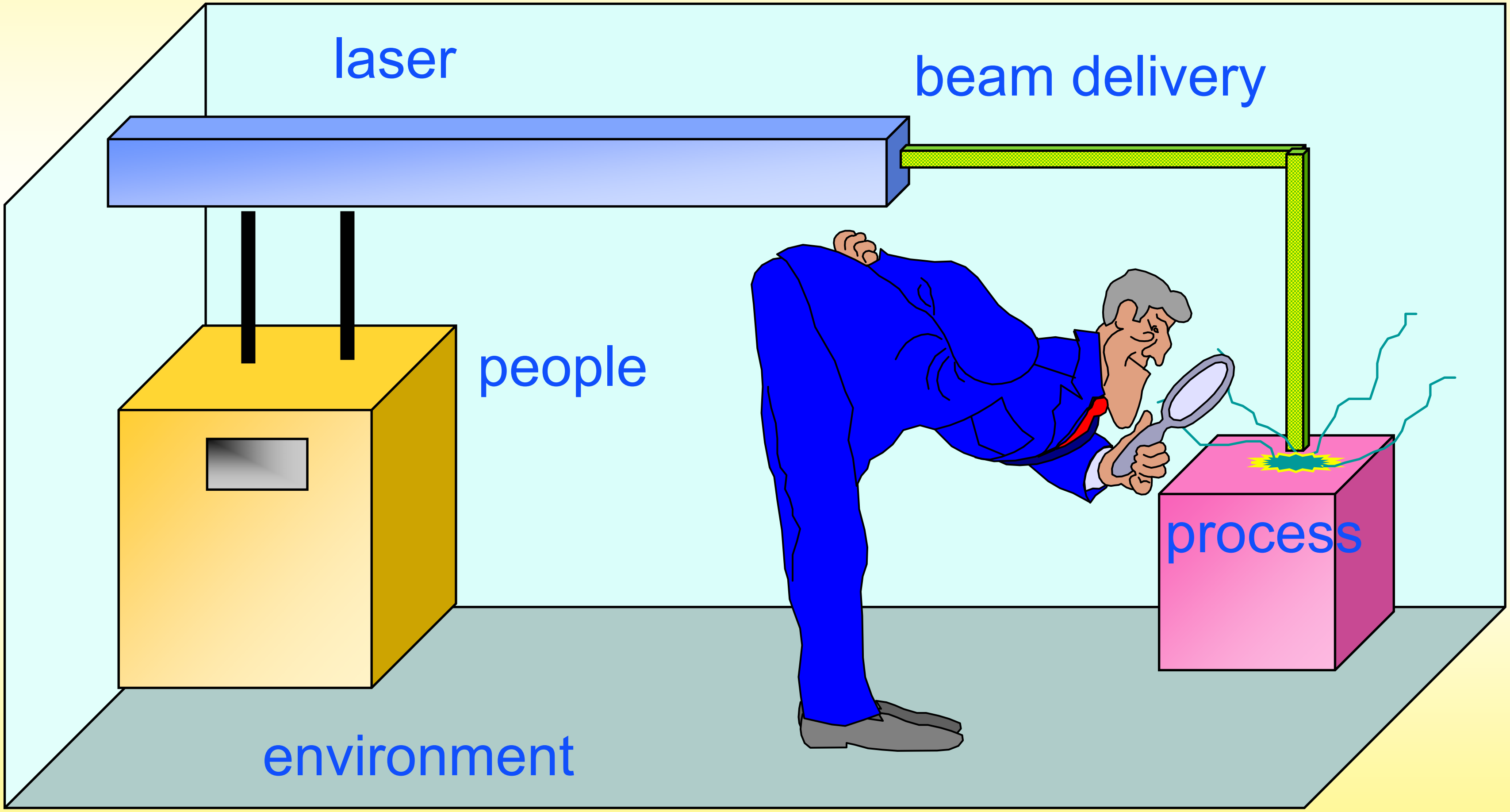
Laser Radiation Safety
John O'Hagan and Ken Barat


Laser Safety?
Laser
This Way Up

Life Cycle

- Planning
- Design
- Manufacture
- Testing
- Transport
- Installation
- Commissioning
- Normal Operation
- Fault Conditions
- Maintenance
- Servicing
- Modification
- Decommissioning
- Disposal

Laser Application - model



Laser Application Model

- Some applications will have multiple lasers, beam delivery systems and processes
- Systematic review is important
- Not complicated!


COHERENT

Class 1 Laser Products

Class 1 Laser Product

Box
containing
laser,
beam delivery
& process

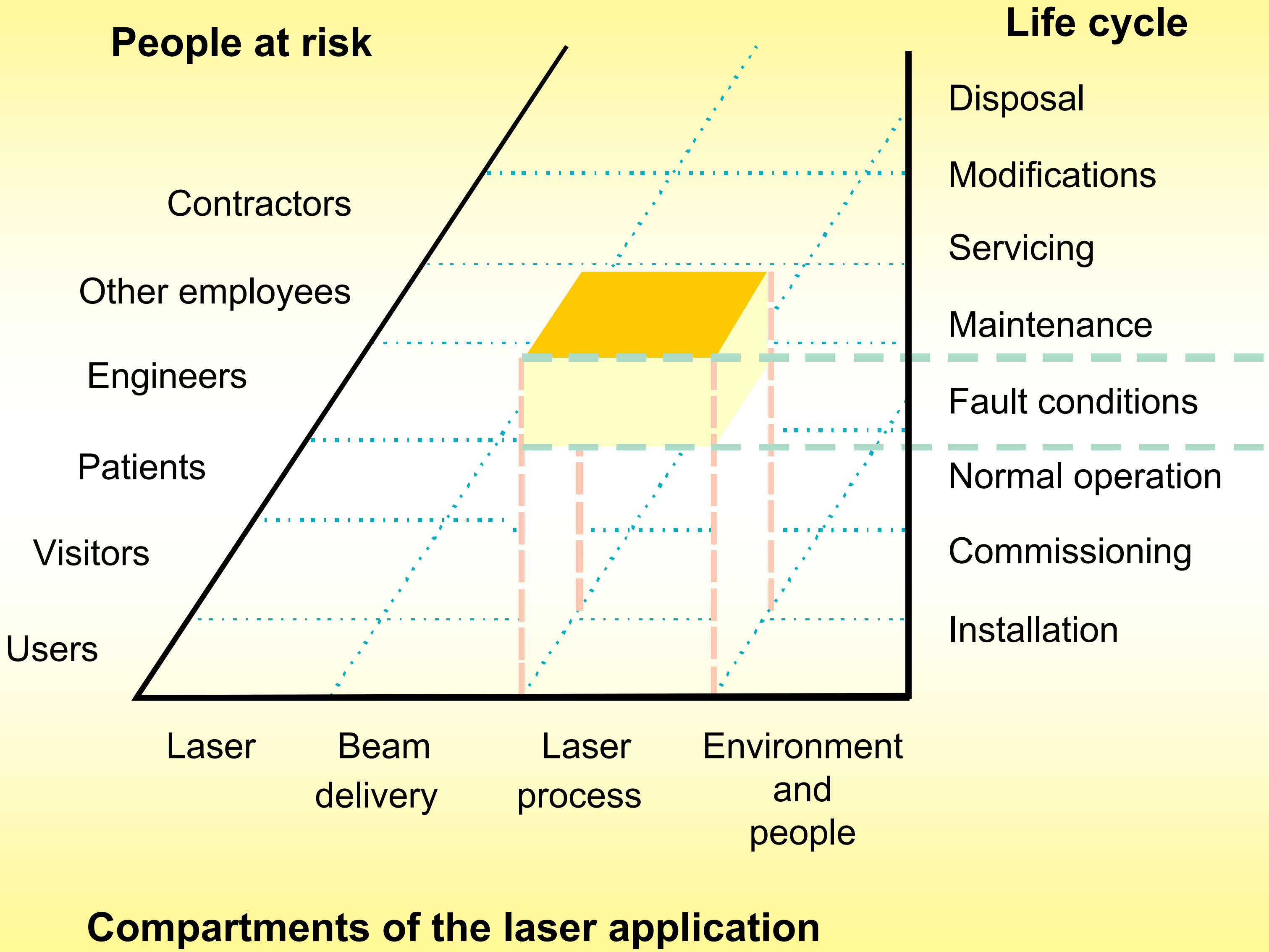
BUT - does it always?
- Review life cycle.

Life Cycle

- Planning
- Design
- Manufacture
- Testing
- Transport
- Installation
- Commissioning
- Normal Operation
- Fault Conditions
- Maintenance
- Servicing
- Modification
- Decommissioning
- Disposal

Identify Hazards

- Optical radiation
- Electrical
- Chemical
- Mechanical/Ergonomic
- Temperature/Fire
- X-Ray/Electromagnetic Interference



People at risk

Contractors

Other employees

Engineers

Patients

Visitors

Users

Life cycle

Disposal

Modifications

Servicing

Maintenance

Fault conditions

Normal operation

Commissioning

Installation

Laser

Beam delivery

Laser process

Environment and people

Compartments of the laser application

Example

- Neodymium:YAG laser
  - frequency-doubled
  - 532 nm
- Flashlamp pumped
- Diode pumped
- Application not important initially

Nd:YAG Laser Safety Issues

- Consider from the aperture back to the “service” connections
- Optical radiation
- Electrical, Chemical
- Mechanical/Ergonomic
- Temperature/Fire
- X-Ray/Electromagnetic Interference

Beam Delivery

- Open Air
- Beam tube
- Fibre
- Robotic Arm
  - Depends on application

Process

- What is the laser beam doing?
  - Heating
  - Exciting
  - Reflecting
  - Transmitting
- Depends on application

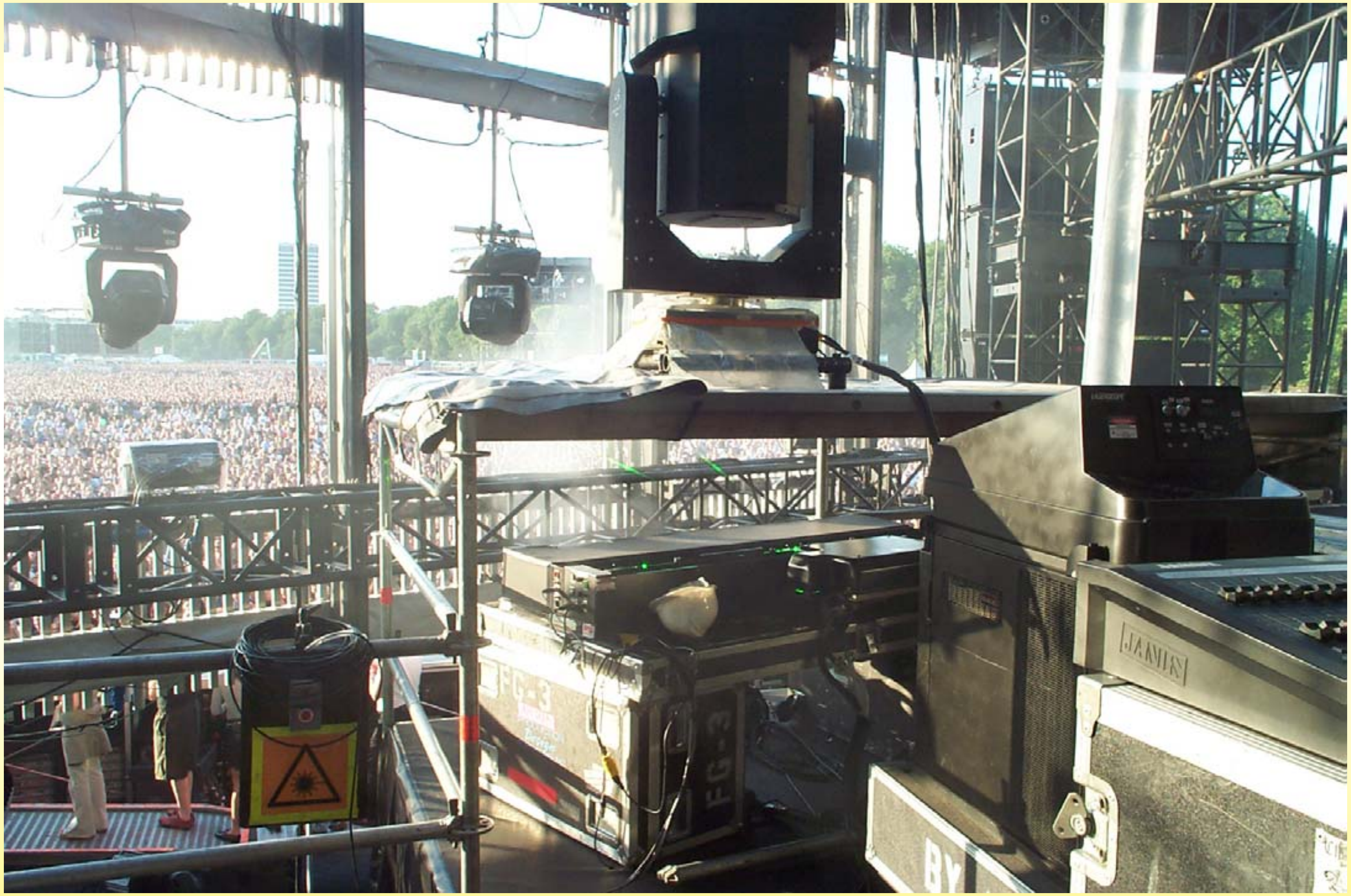
Environment

- Where is the application?
  - In a “box”
  - In a room
    - laboratory, clean room
    - medical facility, beauty salon
    - manufacturing area
  - Outdoors
  - In the home

People

- Who can influence the safety?
- Not necessarily those at risk
  - operator
  - support staff
  - managers
- Depends on environment

Medical Nd:YAG Laser



Medical Nd:YAG Laser

How to Manage the Risk

- Engineering Controls
  - physically restrict access
- Administrative Controls
  - tell people not to go near
- Personal Protective Equipment
  - shield people directly

Nd:YAG Lasers in the Home

Application: Industrial Research Medical

Control:

- Standard Operating Procedures
- Training
- Authorised Personnel
- Alignment Procedures
- Warning Signs
- Engineering Controls
- Protective Housing
- Beam Path
- Activation Warning Sign
- Indoor Controls
- Temporary Control Area

Summary

- Laser Hazard Methodology
  - life cycle
  - laser, beam delivery, process, environment & people
  - people at risk
- Nd:YAG example