THE IDENTIFICATION OF OCCUPATIONAL EXPOSURE TO LASER RADIATION IN GREECE

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Abstract

Introduction: Optical radiation includes the UV, the IR and the visible regions of the electromagnetic spectrum. The relevant occupational exposure legislation, Directive 2006/25/EC, employs limits and Occupational Health & Safety (OHS) regulations for laser (coherent) and non-coherent artificial optical radiation (AOR).

Purpose: Although ten years have passed from the release of the Directive, poor progress has been made towards its practical implementation, mainly regarding the conduction of integrated risk assessments by qualified experts. The Hellenic Ministry of Labor, following a satisfactory non-coherent AOR survey, in conjunction with the National Technical University of Athens and the Greek Atomic Energy Commission, took the initiative to identify the field.

Materials and Methods: Lasers are widespread mainly in health care facilities, industry, cosmetics, research and entertainment installations. Selected workplaces have been chosen for the evaluation of their OHS approach applied and for measurements of the appropriate optical quantities, under realistic exposure scenarios. The role of the Laser Safety Officer (LSO) has been discussed as well.

Results: Initial effort has been performed to map the extent of laser applications in Greece, starting from testing selected crucial workplaces, as representative pilot studies. First assessment in cosmetics, in a research lab and in material processing industry revealed overexposures and safety gaps.

Conclusions: The overexposures and the misapplication of the safety procedures detected, justify the need for actions by the involved Authorities.

1. Introduction

Coherent and non-coherent optical radiation (OR), part of the electromagnetic spectrum, covers the ultraviolet (UV), the infrared (IR) and the visible (VIS) spectral regions. The term optical is used due to the fact that this radiation follows the laws of geometrical optics. After the discovery of coherent artificial light in 1960, lasers are widespread mainly in health care facilities, industry, metrology, cosmetic applications, education and research, as well as in entertainment installations, but there is no a homogenized safety approach worldwide. A number of national and international professionals have recommended occupational or public exposure limits and guidelines for optical radiation, while the continuous laser technology novelties demand their revision from time to time, in an updated form.

In European countries the most recent occupational exposure legislation, Directive 2006/25/EC, employs limits and Occupational Health & Safety (OHS) regulations for laser (coherent) and non-coherent artificial optical radiation (AOR). This specific Occupational Health & Safety (OHS) Directive attempts to homogenize the existing, if any, national safety rules of the Member States (MS) of European Union (EU), dealing with both the target organs, the eyes and the skin. However, after the first years of the Directive's implementation, the criticism on its complexity, stated for its non-coherent part, was also sustained for the laser one **[1].**

Greece has implemented the AOR Directive into national legislation under the presidential decree 82/2010. However, even though the Directive has been released in 2006 and the Greek legislation in 2010, poor progress has been made towards its practical implementation regarding the conduction of integrated risk assessments by qualified experts. The identification of another, highly specialized OHS gap, prompted the OHS Directorate of the Hellenic Ministry of Labor, the National Technical University of Athens (NTUA) and the Greek Atomic Energy Commission (GAEC) to estimate the extend of occupational exposure from laser AOR **[2]**. More specifically, an effort was made to: i) identify the possible sources and installations where workers might be exposed to lasers countrywide and ii) measure the appropriate optical physical quantities identified by the Directive, under possible hazard scenarios. Along with the measurements, an overall OHS assessment was conducted, through dedicated checklists, in accordance with the OHS principles and regulations.

A lot of experience has been accumulated from the occupational exposure assessment of the Electromagnetic Fields (EMF) **[3]**, along with the most related non-coherent AOR **[1]**. This invested knowledge is expanded to face the laser peculiarities. Some of them are: i) the unique physical characteristics of laser light; ii) the enormous extend of very different laser applications; iii) the potential power of some lasers and the consequent hazards they imply; and iv) the lack of an overall national wide safety management. This last one reveals that laser hazards, many times, are neglected or underestimated because the technical precautions applied are considered sufficient.

The aim of this preliminary study was to assess the implementation extent of the laser safety procedures and the use of protective measures in certain areas of application, as well as to identify the probability and frequency of overexposures; only the laser beam safety issues were treated.

Additionally, future objectives of the presented effort are:

- Mapping of the various laser applications.
- Creation of dedicated sample safety checklist.
- Implementation of pilot safety procedures for certain laser installations,
- Activation of the laser safety experts.
- Clarification of the medical laser applications and safety issues and development of QA protocols.
- Legislative upgrade.

The extent of different laser applications and the first sample results revealed that the laser OHS demands enhanced attention and an integrated safety approach **[2]**.

2. Laser safety guidelines and practical considerations

2.1 The diversity of laser applications and their relevance to laser safety

Nowadays, lasers are present in many workplaces and often the workers don't even know about this technology, overestimating or, in contrary, underestimating any laser safety rules. Apart from their initial applications (mainly in research and military applications), lasers are widespread in hospitals (ophthalmology, refractive surgery, photodynamic therapy, dermatology, laser scalpel, vascular surgery, dentistry, medical diagnostics), in material processing - industry (cutting, welding, laser marking, drilling, photolithography, rapid manufacturing), in low power laser applications (physiotherapy, cosmetics), in cultural heritage and art restoration, in entertainment (laser shows, laser pointers), in metrology (distance measurement, surveying, laser velocimetry, laser vibrometers, electronic speckle pattern interferometry, optical fiber hydrophones, high speed imaging, particles sizing), in optical information storage (CD/DVD, laser printers) and also in communications, holography and spectroscopy. It seems that laser-based applications could be found in every field.
Recently, ultra-fast pulsed lasers are even developed in a series of optimistic transnational current projects involving lasers in fusion or to produce and accelerate ionizing particles that could be used for proton cancer treatment **[4]**.
Recalling the rich diversity of laser applications, it is very important to clarify the relevant safety rules, in order to eliminate or to minimize any accidental use. It is very common to hear that in all aspects of laboratory, field or industrial safety, the best measures are the positive attitude and the common sense; however, the unique characteristics of these new artificial light sources are in the same time the source of spectacular novel applications, as well as the cause of 'unpredictable' laser accidents.
In any field of laser applications, laser hazards can be considered as immediate, having to do with the laser device, and indirect, having to do with the specific laser application. Immediate hazards are connected, for example, to the electrical parts of the laser device (capacitor's discharge, electrocution, sparks, explosion, fire) or to the toxic gas products used either as cryogenics liquids or as active materials of the laser (i.e. fluorine and hydrogen chloride used in excimer lasers, dyes used as the optically active medium in some laser). Indirect hazards involve emission of dangerous substances (e.g. operating theatre air contamination with fumes from tissue ablation and charring), ignition of explosive substances (like medical gases), fire or exposure to secondary radiation, but mainly the possible exposure of the eyes and the skin to the direct and the scattered beams.
Every hazard can eventually lead to an accident, the great headache of every laser installation. Worldwide, several national institutions, academic places and non-profit health physics and biomedical technology agencies, record and periodically report laser accidents. For example, by completing the first 50 years after the laser discovery, the Laser Institute of America (LIA) reported the distribution of 50 years' accidents (1960 – 2010) per installation **[5]**. For the first 25 years (1960 - 1985) the accidents mainly involved the scientists working in the development and the operation of the lasers area. The next 25 years (1986 - 2010), the vast majority of the accidents involved medical applications, revealing the great development of the laser medical sector.
7974 accidents (mainly eye injury of involved technicians and scientists) between 1964 and 2010 have been also reported by the Rockwell Laser Incident Database **[6]**.

2.2 The diversity of laser source parameters and their relevance to laser safety

It's really astonishing to keep in mind that the basis of laser is light that mainly is UV, visible and IR photons (in some cases there are even X-ray), produced from certain energy levels of the atoms of the active medium (the 'source' of photons). That active medium and the wavelengths of the emitted photons is one approach to characterize the type of the laser (Figure 1). It is worthy to remark that this classification is just indicative, as many wavelengths may be available from the same laser active medium. The basics of laser physics and the so called 'stimulated emission of radiation', implies that the initially produced photons are put in phase (space and time coherence) that gives them their unique characteristics, as monochromaticity and directionality. Moreover, outside the optical cavity, the collimated laser beams can be further focused to a very small spot size (limited by the lens and the wave nature of light quanta) that increases their power density, or they can diverge passing through optics or waveguides, resulting in a distance dependence of any laser action effects. Another important physical parameter for the lasers is that they may function continuously (CW – continuous wave) or in pulses of different pulse durations (short pulses imply high energies per pulse).

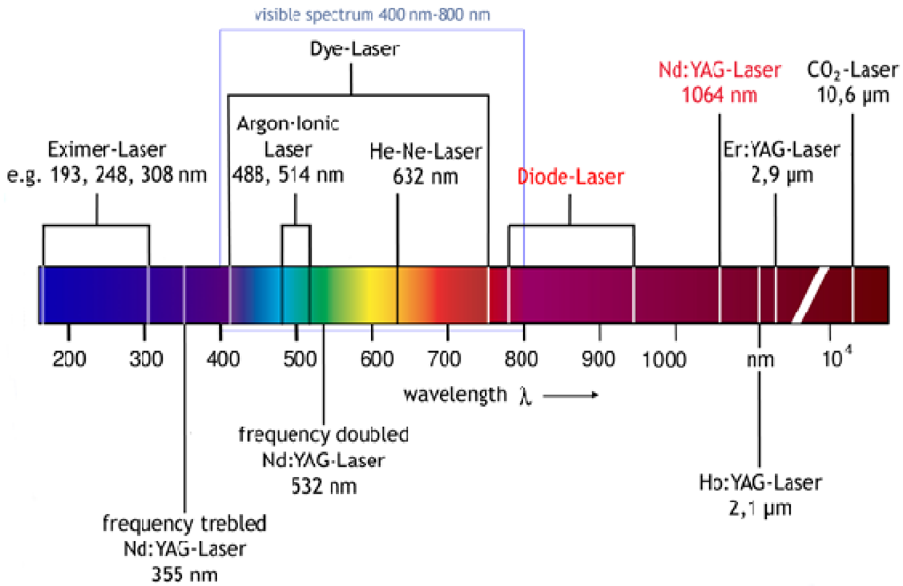

Figure1. Most commonly used laser types over the optical spectrum; many wavelengths may be available from the same active medium.

The diversity of the laser source parameters leads also to a complexity in the devices and methods of the laser output measurements, for both the radiation dosimetry and the laser safety issues. In order to measure the laser power and the energy output on a laser installation, the appropriate type of sensor (photodiode, thermal, pyroelectric) or detector (e.g. energy meter or power meter) and the appropriate mode to display the measurement results (oscilloscope, monitor, digital display etc.) should be used. The selection of the appropriate sensor/detector depends on several factors, including: i) the laser type; ii) the laser wavelength(s); iii) the exposure duration; iv) the pulse repetition frequency; v) the beam's power density; and vi) the beam's diameter.
Additionally, for several applications it is useful to specify the distance over which the hazards from optical radiation might extend [**7**]. Especially, if the laser beam diverges,

the distance over which the level of exposure has dropped to acceptable levels, is known as the nominal hazard distance (NOHD): beyond this distance there is no risk.
Some important laser parameters that will be used for the identification of the safety distances are: i) the radiant power (W); ii) the initial beam diameter (m); and iii) the beam divergence (radians).

2.3 OHS Directive 2006/25/EC for AOR

The Occupational Health & Safety (OHS) reveals a demand for social, cultural and economical upgrade, for countries that want to be treated as developed ones **[1, 3]**. Directive 2006/25/EC, as part of the overall OHS legislation, refers to the risks to the health and safety of workers due to adverse effects (hazards) caused by exposure to AOR to the eyes and to the skin, from laser and non-coherent optical radiation.

The main individual in charge to apply in practice OHS, is the Safety Officer (SO) (legislative the main responsibility remains to the employer), whose main OHS tool is the risk assessment; the scientific approach to identify and quantify hazards **[1]** (hazard is anything that can go wrong in the workplace and risk is the possibility of a specific hazard to occur. The upgrade of this 'general' SO to a dedicated Laser Safety Officer (LSO), especially for certain laser installations, is a demand and this survey aims to highlight, along with the need for an overall laser safety management.

The relevant scientific work and the vast experience accumulated over more than 50 years of various laser applications, indicates that adverse health effects due to skin and eye accidental exposure to laser radiation are potentially possible across the entire optical spectrum: from 180 nm in the ultraviolet (UV) to 1 mm in the far infrared (IR). Nevertheless, the risk of retinal injury due to the visible and near IR regions (400 to 1,400 nm) is of particular concern **[8]**. Without doubt, the same mechanisms of laser radiation interaction with biological tissue, that are the basis of both therapeutic and diagnostic biophotonics applications, are also the source of laser damage, in the case of accidental exposure. Laser biological effects are the result of one or more competing biophysical interaction mechanisms, categorized as: photochemical, photothermal, and photomechanical (photo-disruption, photo-acoustic and optical breakdown). The photo-damage effects vary depending upon spectral region and exposure duration. Briefly, the undesired photobiological effects are: i) for the UV region mainly photochemical and thermal damage of the eyes and erythema of the skin; ii) for the visible region photochemical and retinal damage of the eyes and thermal damage of the skin; and finally iii) for the IR region thermal damage for the eyes and the skin **[7]**.

According to the above mentioned mechanisms, the 2006/25/EC Directive covers the following regions for coherent (laser) and non-coherent AOR **[7]**: (i) ultraviolet radiation, divided into UVA (315 - 400 nm), UVB (280 - 315 nm) and UVC (100 - 280 nm), (ii) visible radiation, ranging between 380 nm and 780 nm and (iii) infrared radiation, divided into IRA (780 - 1,400 nm), IRB (1,400 - 3,000 nm) and IRC (3,000 nm - 1 mm). The Directive has its scientific basis on the ICNIRP's (International Commission of Non-Ionizing Radiation Protection) initial AOR guidelines **[9],** which were further amended in 2006 **[10]**.

The Directive provides limits, namely Exposure Limit Values (ELVs), for all the above regions, based directly on established health effects and photobiological considerations; compliance to the ELVs ensures that the workers are protected against all known adverse health effects. Finally, in order to facilitate its implementation, an extended and useful practical guide that contains theory, practical solutions, references and OHS management approach, is available **[11]**.

2.4. Exposure limits for optical radiation - quantities and units

The exposure limits depend on the laser emission wavelength(s), the exposure duration (pulse duration in pulsed systems), and in some cases on the spot size.
The primary questions faced when assessing a laser installation are:

- Is the laser continuous (Continuous Wave - CW)?
- If the laser is in pulsed mode (pulsed), what is the pulse duration?
- What wavelength(s) is/are emitted?
- What are the maximum and minimum energy or power values?
- What is the divergence of the beam?

In order to evaluate the potential optical radiation hazard to the eyes, optical-measurement quantities and units are used, namely the **radiometric** and **photometric** ones. Radiometry deals with the measurement of the entire optical radiation spectrum, while photometry deals only with the visible light. The complex optical radiation terminology and the detailed measurement/calculation procedures are beyond the scope of this work [**12, 13**]. The physical properties of the electromagnetic radiation are characterized by **radiometric units**. Radiometric quantities such as the **radiance** - used to describe the 'brightness' of a source [in $W/cm^2 \cdot sr$] - and the **irradiance** - used to describe the irradiance level on a surface [in W/cm^2] - are particularly useful for hazard analysis. Irradiance is defined as the incident power divided by the area over which the irradiance is determined. Radiance can be interpreted as the irradiance at the point of the detector (averaged over the appropriate area) divided by the field of view (in steradian - sr) of the detector.

The physical quantities used to express ELVs are: (i) irradiance (E) or power density, defined as the radiant power incident per unit area upon a surface, expressed in Wm^{-2}, (ii) radiant exposure (H) defined as the time integral of the irradiance, expressed in Jm^{-2} and (iii) (integrated) radiance (L) defined as the radiant flux or power output per unit solid angle per unit area, expressed in $Wm^{-2}sr^{-1}$.

The ELVs for the laser optical radiation are given in tables of the Annex II of the Directive that combine pulse duration and wavelength **[7]**. These ELVs take into consideration the biological effectiveness of the optical radiation to cause damage at the various wavelengths, the duration of the exposure and the target tissues. For exposure times <10s the ELVs for the eyes are given in table 2.2 of Annex II, while the ELVs for the skin exposure are given in table 2.4.

The ELVs are used in conjunction with correction factors and calculation parameters, like C_A, C_B, C_C and C_E, given in table 2.5 of Annex II [**7**]. There are also corrections for repetitive pulses in table 2.6.

The applicable ELV for the tested installations was the radiant exposure - H (J/m^2).

ELV is sometimes (equivalently) expressed as MPE (maximum permissible exposure) in terms of time **[14]**.

2.5 Laser safety standardization – a brief overview

Despite the fact that the use of laser sources covers several fields of everyday life, laser safety often receives less attention than other ionizing and non-ionizing radiation safety and health issues; this hold for both the laser professionals and the authorities. This reduced attention occurs despite the fact that the potential for laser-related occupational injuries is much greater than the potential for injury from radioactive materials [**15**], especially in healthcare where well-established medical physics procedures are present. Therefore, the development of a laser hazard evaluation procedure, with the adequate safety controls, is a prerequisite in any laser installation.

A number of worldwide reports on the basis of an overall occupational laser safety management, point out that recording, classification, evaluation and re-evaluation of the laser systems is definitely demanded **[11, 15, 16]**. Unfortunately, in Greece there are only a few initiatives regarding the development and implementation of a laser safety program. Evidently, the lack of laser safety management guidelines allows certain organizations and laser trade companies to claim they can provide accreditation for the laser safety officers (LSOs) **[17, 18, 19, 20, 21]**. An official and sound agency (or authority) that could give accreditation on laser safety is a great OHS demand. An interesting occupational survey from Greece, using questionnaires, reports OHS gaps in laser ophthalmology departments **[22]**. It was stated that about one third of the laser operators were not trained on OHS, another third were trained by unofficial agencies, while the rest of them were not aware of the presence of the personal protective equipment (PPE). Only one third believed that they were sufficiently protected against laser hazards.

The general OHS tool of risk assessment can (and must) be also specified for laser applications; an initial general approach to evaluate the risk is as follows **[11]**:

- Decision about which sources are ‘trivial’ that is they don’t pose any significant hazard (using laser classification and nominal ocular hazard distance - NOHD).
- Decision about exposure scenarios and which of them need further assessment.
- Assessment of the exposure, if needed, against ELVs.
- Consideration about exposure to multiple sources.
- Actions, if the ELVs are likely to be exceeded.
- Recording of the significant conclusions **[23]**.

<u>Laser safety classification:</u> The classification of lasers takes into account the output of the laser device, as well as the human access to their light emission. Lasers are grouped into seven classes: 1, 1M, 2, 2M, 3R, 3B, and 4, whereas the higher the class, the bigger the potential to cause harm. This classification doesn’t take into account additional, non-beam hazards (e.g. electrical or chemical hazards, fume, noise, etc). Laser classification (from 1 to 4) is the initial safety step in order to decide which systems need further assessment **[14, 15, 24]**. Note that even the closed class 1 lasers, under maintenance procedures, may pose hazards as workers are exposed to open beams.

The installations tested in this survey were 3B and 4 classes.

<u>Nominal hazard distance (NOHD):</u> The laser beam diverges from it source and at some distance the irradiance will equal the ELV for the eyes. This distance is called the Nominal Ocular Hazard Distance (NOHD), which is the distance below which the

exposures might exceed ELV (or the Maximum Permissible Exposure - MPE) and must be identified by appropriate signaling **[15, 25]**. This distance or equivalently the NOHA (nominal ocular hazard area), is either provided by manufacturers with product specification, or can be calculated for Gaussian or quasi-Gaussian beams by (Equation 1), using the laser output specifications (radiant power, initial beam diameter and beam divergence):

$$NOHD = \frac{\sqrt{\frac{4 \times radiant\ power}{\pi \times ELV}} - initial\ beam\ diameter}{beam\ divergence} \qquad (1)$$

Part of the risk assessment is also the suggestion for the application of possible corrective actions. These control measures escalate from engineering and administrative controls to personal protective equipment (PPE) **[11]**.
Some of the available engineering controls, applicable directly to the laser source, involve protective housing, enclosures, interlocks, delayed operation switches, warning lights, audio signals, remote controls, alignment aids, attenuators, shutters, viewing and filtered windows, elimination of reflections, access prevention and emergency stops.
Administrative controls involve mainly the appointment of a competent laser safety officer (LSO) and consequently the documentation of the safety management, local rules, checklists, controlled area specifications, safety signs and notices, training of employees, consultation & participation of the employees to the OHS procedures.

3. Laser safety measurements – pilot studies

3.1. Methodology

In order to apply laser OHS in practice, several laser standards are available **[8, 10, 26, 27]**. They can be either European (IEC), or from the USA (ANSI). As the laser safety standards are many, questions have been raised about their applicability. The safety approach determined in this survey, tries to simplify the field. The first step was an effort (that is still in progress) to map the extent of laser applications in Greece, together with an initial testing of selected pilot workplaces, as representative implementation studies; their performed safety assessment was made through appropriate checklists that were developed on the basis of OHS principles and regulations (**Figure 2**). The recorded aspects range from laser classification and nominal output to safety training of the personnel and control measures.

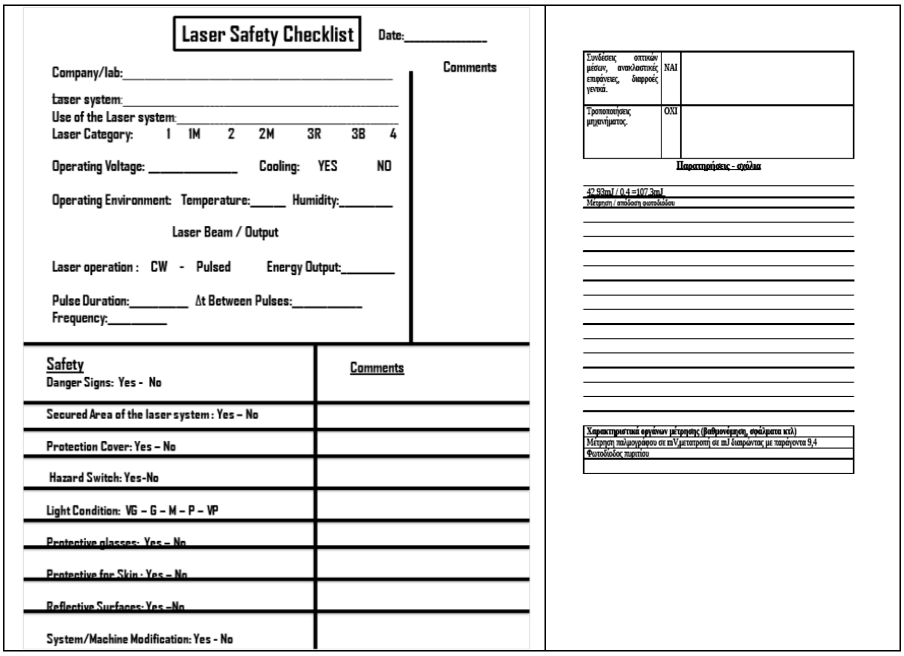

Figure 2. Checklists developed for the safety assessment of the selected laser installations.

Probably the most demanding part of the survey was the measurement of the appropriate optical quantities under the development of realistic exposure scenarios that try to investigate and imitate possible accidents.

The measuring equipment comprised of different hand held digital and oscilloscope driven energy meters (**Figure 3**), special laboratory oscilloscopes, a digital photometer and a digital thermohydrometer, appropriately calibrated. In this direction, the initial oscilloscope's voltage output was converted in Joules, using the conversion factor of the energy meter. Finally, using the beam's diameter or the energy meter's active surface, the radiant exposure H (J/m^2) was calculated. Results were compared to the appropriate Directive's ELVs.

Figure 3. Energy meter connected to an oscilloscope and the voltage readout.

Of course no one expects to be exposed intentionally to the main beam of a laser and thus the most common scenario implies the exposure to the reflected or scattered beams. In the case of exposure to the main beam, rather as a result of an accident, there is substantial overexposure for all laser light sources. On the other hand, concerning scattered beam exposure, several issues like the characteristics of the reflecting material and the overall geometry have to be taken into account. More accurately, many scattered beams have to be considered (**Figure 4**). Additionally, it's important to keep in mind that the reflectivity of a material has to do with the wavelength; a surface could be dark in a spectral range, or highly scattering in another. Proper exposure scenarios have to identify and measure both the main and the scattered beam exposures.

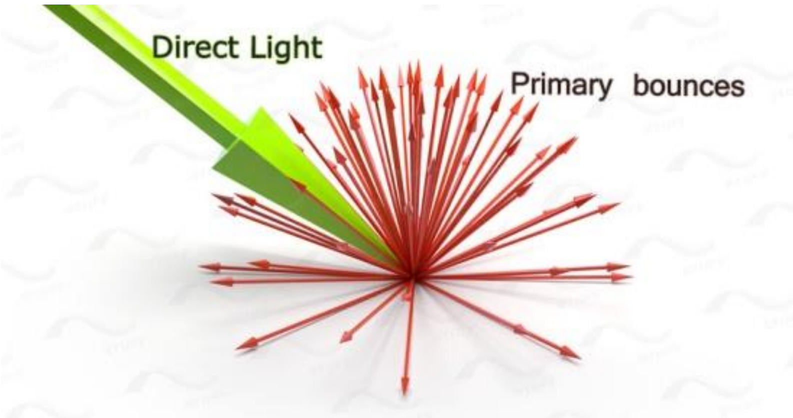

Figure 4. Specular (catoptric) and diffuse reflection.

Environmental conditions, temperature and humidity, were measured when possible, due to their dependence to the proper function of the laser system. The ambient lighting conditions are correlated to the opening of the pupil of the eye and thus with the potential retinal hazard; proper lighting conditions are estimated to about 500 Lux that correspond to normal office conditions **[28]**.

Personal protective equipment (PPE), even the last OHS action, is of great importance at distances below NOHD. Concerning the main PPE for the eyes, i.e. the safety glasses, the first parameter to be taken into account is the optical density (OD or attenuation) for every wavelength that the laser emits; OD is defined as the logarithmic ratio of the incident radiation to the transmitted radiation through a material, at a specific wavelength or ranges of wavelengths.
The selection procedure of the proper eye PPE follows certain steps [**11, 29, 30]**, while several free OD calculators are accessible **[31]**.
As a general OHS approaches, all hazards present in the working environment have to be taken into account and PPE has to be adequately adapted to all of them. Safety glasses should not add more hazards than the ones they protect from, meaning that apart from the OD other aspects (like luminous transmittance, color perception and reflections) have to be taken into consideration. Sometimes, special conditions concerning PPE have also to be considered as their properties have to comply with the occupational peculiarities **[32].**
In general, AOR safety should be managed through the same OHS management structure as all the other potentially hazardous activities **[11]**. The details of the organizational arrangements may vary according to the size and structure of the organization. In this sense for many applications, the training of an LSO may not be justified. It may also be difficult for the staff to keep up to date with laser safety if they don’t use their skills frequently. Therefore, some companies make use of an external LSO, who may provide recommendations on: engineering control solutions, written procedures for the safe use of the equipment, operational and occupational safety measures, selection of PPE and staff education and training.
Consequently, the main responsibility of the LSO is the overall management of the safety issues. The LSO must have competent general OHS skills but must also be aware

of all the laser peculiarities. It seems though reasonable that the LSO must have many year of sound education and experience on lasers and laser safety and that a general SO, like in the case of ionizing and non-ionizing radiation **[1]**, is not sufficient.
Finally and in order to supervise the day-to-day aspects of laser safety in a workplace, it might be appropriate, a sufficiently member of the staff or the employee if competent, to be appointed as the LSO.

3.2. Laser installations and device characteristics

Assess, for the time being, was made possible to the following representative installations that is cosmetics, research lab and industrial material processing **[2]**. Measurements and calculations of the radiant exposure H (J/m^2), together with safety assessment were conducted.

3.2.1. Cosmetics

An Nd:YAG hair removal system was tested (**Figure 5**). Apart from the main (invisible) laser beam at λ = 1064 nm (near IR), the system was also equipped with an additional visible tracer beam at λ = 650 nm (red).
The system's specifications were: 10W mean power, 10ms pulse width, 1Hz repetition rate and 4mm beam diameter.

(a) (b)

Figure 5. (a) The workplace of the cosmetic laser installation. (b) Display of the cosmetics laser device specifications.

Measurements of the main 1064nm laser beam were made, reflecting the fact the basic hazard comes from its misuse. No measurements were made under operation on humans and no reflecting scenarios were tested.
The ELVs for the eyes (Equation 2) - (according to table 2.2 of the Directive), for the skin (Equation 3) - (according to table 2.4) and for the wavelength and pulse duration characteristics of the laser, are given below.

$$H_{eye}=9\cdot t^{0.75}\cdot C_C\cdot C_E \ (J/m^2) \qquad (2)$$

$$H_{skin}=1.1\cdot 10^4\cdot C_A\cdot t^{0.25} \ (J/m^2) \qquad (3)$$

According to the table 2.5 of the Directive and the applied wavelengths, $C_C = C_E = 1$ and $C_A = 5$.

3.2.2. Research lab

An Nd:YAG research laser system of nominal output, 6ns pulse width, and 1Hz repetition rate, was tested (Figure 6).

Figure 6. The energy meter is seen behind the lens that focuses the laser beam output.

The ELVs for the eyes (equation 4) - (table 2.2), for the skin (equation 5) - (table 2.4) and for the wavelength and pulse duration characteristics of the laser are given below.

$$H_{eye}=5\cdot 10^{-2}\cdot C_C\cdot C_E \ (J/m^2) \qquad (4)$$
$$H_{skin}=200\cdot C_A (J/m^2) \qquad (5)$$

According to the table 2.5 and the applied wavelengths, $C_C = C_E = 1$ and $C_A = 5$. Scattered beams scenarios for three different materials (wafer, blacked Plexiglas and anodized aluminum) were developed and the angular distribution was tabulated.

3.2.3. Industry – material processing

A vivid, solar heater industrial construction was assessed (**Figure 7**). The main laser installation was a double head Nd:YAG laser, at wavelength 1064nm, 500W mean power, 2.4J pulse energy, 0.3ms pulse width, 155 Hz repetition rate.

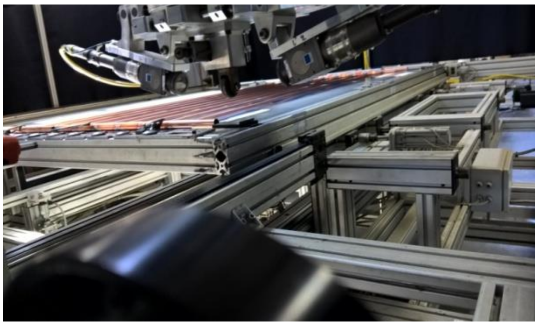

Figure 7. A double head Nd:YAG industrial laser system under operation. The energy meter is seen in front.

The ELVs for the eye and for the skin are given by Equations (2) and (3).

4. RESULTS

4.1. Cosmetics lab

The nominal output for the primary beam was 15 J/cm^2, which was verified to be 14.9 J/cm^2 using the handheld Ophir Nova II energy meter. This value is 52,000 times over the limit for the eye per pulse (Equation 2) and 8.5 times over the limit for the skin per pulse (Equation 3) **[2]**. This measurement is a kind of QA (quality assurance), since it implies a verification of the laser functional characteristics.
Concerning safety, there were no signaling, no curtains and there were a lot of reflecting and/or transmitting surfaces around (Figure 5a). Safety glasses of the appropriate OD were available, but no gloves. There were no appointed LSO and there were no reported OHS training of the personnel.

4.2 Research lab

Primary beam's nominal output was verified to be 120 mJ and 126 mJ using two different oscilloscope driven energy meters.
Concerning safety, there were signaling, may be not as big as it would be appropriate, but no curtains, there were a lot of reflecting surfaces and some kind of interlocks was available. Safety glasses with the appropriate OD were available, but no gloves. There were an appointed LSO and training of the personnel had been committed. The lab is also used for studying and PC use, setting the need for advanced safety assessment. The environmental conditions in lab were: humidity 55%, temperature 27^{o}C and the ambient lighting was 250 Lux.
The scenarios developed for the reflecting beam and for three different materials gave the following angular distributions (Figure 8):

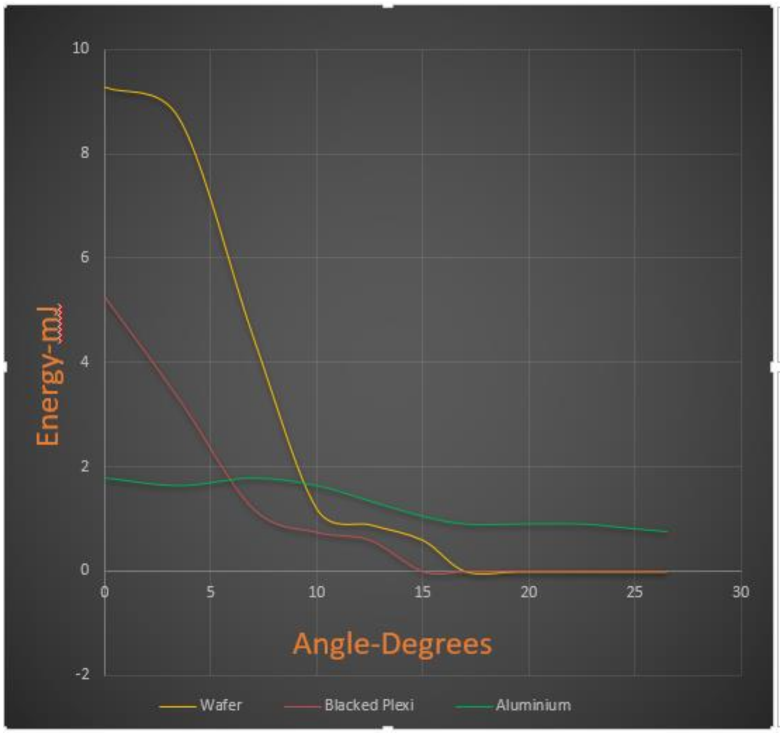

Figure 8. Measurements of the scattered beam's energy (mJ), for different angles from catoptric reflection and for three different materials.

The safety distance for the worst case catoptric reflection (Equation 1 - NOHD approach) was calculated to be approximately 2m**.** The safety distance for diffuse reflection was calculated to approximately 0.6m **[2].**

4.3. Industry

Due to the geometry of the double head laser system that moves fast along the welding area, only the scattered beams at the opening of the safety curtain were measured; that is the most realistic exposure scenario. Scattered beams showed great fluctuation, depending on the angle of the detector. The worst exposure result ranged up to 25 times over eye limit and 0.1% of the skin limits **[2]**. The environmental conditions were measured as: humidity 38%, temperature 29^{o}C and the lighting conditions were approximately 200 Lux.
Concerning safety, certain solutions were active: signaling, protective curtains, warning lights (Figure 9), emergency buttons, PPE (OD>7) and the employer was the appointed LSO. But there were no interlocks, certain reflecting metal surfaces were present, the personnel didn't make use of the PPE and the risk assessment was pending.

Figure 9. Protective curtain (and the opening), signaling and warning light for the industrial laser system (on the left). Another, not tested, smaller system is seen on the right.

5. Discussion

The objectives of the presented preliminary study were not only to identify occupational laser exposure, but also to raise the need for OHS procedures in national level. The first axis of the survey (the identification of occupational laser exposure) has also two aims: to map the extent of occupational laser use and to assess certain characteristic workplaces, creating pilot safety procedures for them. This was made possible through the creation of sample safety checklists, the measurement of the appropriate optical quantities and the identification of safety distances and procedures.
The laser safety measurements and the application of the Directive's corresponding limits (ELVs) are both a difficult task, but are possible. Recently, late in 2015, an evaluation of the practical implementation of the Directive 2006/25/EC was reported, where one of the overall conclusions was that the AOR Directive appears to attract more diverse and extreme views than most, if not all, of the other EU Directives, while there is clearly no consensus over its need and value. However, the presented findings set a sound and rather new basis to approach laser OHS. Different exposure scenarios,

concerning the primary and the reflected beams were applied. Especially for the case of the reflected/scattered beams different materials and measuring angles were tested in the controlled environment of the research lab. In any case, the geometry of the reflecting beam was very crucial for the determination of a possible accident scenario, which seems rather rare, but it is possible. The scattered beam's measuring approach was to try to identify not only the worst case scenario, but also the common one.

Initial results reveal that the potential eye hazard was present in the assessed installations, even from the scattered beams. Additionally, safety assessment showed that safety procedures were not always followed; may be because hazards are neglected or underestimated. The lack of an appointed LSO and of approved OHS procedures, like engineering and administrative controls (PPE were present), training of the personnel and the not available periodic measurements, as part of an integrated risk assessment, seem to be the reasons.

For the cosmetics application, the primary beam' s (possible) overexposure for the eyes is many thousand times over the corresponding ELV and even if this is not a very realistic risk assessment scenario, the magnitude of the overexposure reveals the degree of the potential hazard. The primary beam also revealed overexposure for the skin. This is might be a demand of the treating procedure, but also poses hazards for the occupationally involved laser operator. Safety procedures were very poor, including large reflecting or transmitting surfaces, multiplying the feeling that primary beam's enormous overexposure was neglected. Measurements for the scattered beams were not conducted, as it was not clear what the proper scenario would be. Moreover this implies the presence of a human treated in real time that, by this time, it was not an objective.

For the research lab application, it was possible to create different scenarios for reflections. It was quite astonishing that the worst case approach gave a hazard distance (NOHD) of 2m and the quite more realistic approach of 0.6m. These findings state that in the lab, the safety glasses must be always worn when the lasers are active and other activities like studying are not to be held in parallel without precautions. Many safety procedures, starting from the appointment of a competent LSO and his corresponding actions, were active, but the measurement results revealed that there is more to be done.

The industry application, the most powerful installation assessed, had the most active safety procedures, justifying the feeling the 'big' installations are set in way to ensure safety. In other words, due to their high outputs and busy production line activities, this is a straightforward procedure. Consequently, the measured results, as a rare exposure scenario, were rather safe. This happens, not only due to the safety controls applied, but also due to the geometry of the system. It is important to state that, even under these conditions, it was made possible to measure some overexposures for very specific angles and right at the opening of the safety curtain. This means that even if the risk is very low, it exists. OHS was active in general, but there was a demand for the specific tasks of the LSO, starting from conducting the integrated risk assessment; measurements are the active part of it.

In general, findings revealed the need to activate and improve safety procedures in laser applications. The Directive 2006/ 25/EC is applicable and the practical guide gives handy information and solutions. The role of the LSO has to be improved, beyond the appointment of a 'general' SO, and specified for the laser applications when needed. His activation can raise issues like training of the personnel, written instruction, appropriate signaling, interlocks, specification of the NOHD, proper selection, maintenance and prompt use of PPE.

The accreditation of the LSO is a great, open issue that has to be treated in terms of an overall laser safety management. When the occupational laser exposure mapping is completed, accreditation should be set in a sound legislative basis. The overall legislative upgrade of laser safety is also under consideration, but what is rather more important now, is the activation of the present legislation and the OHS practice; there are many applicable solutions, e.g. the low lighting conditions detected could be improved at low cost.
Maintenance of laser systems, like all maintenance procedures, is a high risk OHS activity. Even class 1 systems could be hazardous and the identification of complete maintenance exposure scenarios is challenging.

6. Conclusions and perspectives

Various representative laser installations were assessed, as a first step, towards an integrated occupational exposure mapping of laser radiation. Measurements of the appropriate safety optical quantities and comparison to the corresponding Directive's limits (ELVs) are possible. Main and scattered beam measurements revealed eye and skin overexposures that demand further attention; the misapplication of the OHS procedures detected, justifies the concern.
The appointment of a competent LSO to certain installations and his corresponding tasks (e.g. laser characterization, risk assessment, training, engineering and administrative controls, proper use of PPE) shall contribute to the overall laser safety management that seems to be a national wide demand. Accreditation of the LSO reveals gaps that need to be covered by legislation.
Major concern is to assess medical lasers, as they are reported as the most hazardous installations in the late laser era [**6**], which is scheduled to be done soon in the complex hospital environment. The objective to create sample risk assessments and QA protocols remains. The investigation of the vague field of laser entertainment is also of first priority.

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