Risk for general public in the use of handheld laser pointers

Rischio per il pubblico nell'uso di puntatori laser

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Four handheld laser pointers, randomly found on market benches in Italy, were tested comparing the information provided in the safety labels (when present) with actual power and wavelength output. Three out of the four lasers claimed compliance with the American Food and Drug Administration Standard which, for handheld pointers allows higher power levels than permitted by the Italian regulation. In the case of the green pointer, relevant emission at 1064 nm was measured, including a thermal damage risk that could trigger fires in particular situations. All the tested devices showed Accessible Energy Levels higher than expected, even if depending on the charge of the batteries, and well above the exposure limit values established by the International Commission on Non Ionizing Radiation Protection (ICNIRP).

Key words: Laser, pointers, risk, visible

Sono stati verificati quattro puntatori laser reperiti in mercati pubblici scelti a caso in diverse città italiane, confrontando le informazioni fornite dalle etichette di sicurezza (quando presenti) con le effettive potenze e lunghezze d'onda emesse. Per tre dei Quattro puntatori era dichiarata la conformità alla regolamentazione americana della Food and Drug Administration la quale, per i puntatori laser, permette un livello di emissione accessibile superiore a quello ammesso dalla normativa italiana. Nel caso del puntatore verde, è stata misurata un'emissione significativa a 1064 nm che comporta un rischio di danno termico e potrebbe, in condizioni particolari, innescare incendi. Tutti i dispositivi esaminati hanno mostrato Livelli di Emissione Accessibile superiori a quanto atteso sebbene dipendenti dalla carica delle batterie, e ampiamente superiori ai valori limite di esposizione stabiliti dalla International Commission on Non Ionizing Radiation Protection (ICNIRP).

Introduction: legal framework

Injuries from laser pointers are widely described in literature [Gregory et al., 2014] from the medical point of view; in these publications greater detail is provided about the type of lesion, rather than the characteristics of the laser sources. Laser pointers are not toys, and at least it should be established, that it is not advisable to buy laser pointers in booths on the market place. Nonetheless, it could be very useful to consider some technical features of these devices, starting from the regulations on laser sources, that in general are poorly known even among safety professionals. Most of health and safety staffs, share a generic awareness that class III and IV (whatever it means) laser devices require a specialized risk assessment made by a laser safety officer, but are generally less concerned about lower classes devices. Actually, when available, there are two kinds of safety labels that can be found on laser pointers: those derived from Title 21 of the United States of America Code of Federal Regulations (CFR 21) [USA, CFR1040.10] and those derived from International Electro-technical Commission (IEC) Standard 60825-1 [IEC, 2014]. In European countries, IEC applies, according to Directive 2006/25/EU. Even the Food and Drug Administration (FDA), is planning to get compliance to IEC [FDA, 2007], but so far both standards should be taken into account, at least for comparison. According to FDA, laser pointers should not have an Accessible Emission Level (AEL) exceeding 5 mW, as in CFR 21 class IIIa or IEC class 3R.

In Italy, a Regulation of the Ministry of Health [Official Journal of the Italian Republic n. 167] states that *"it is forbidden, throughout the national territory, the marketing of laser pointers or objects with function of pointers, which laser class is equal to or greater than 3"* according to IEC 60825-1. From this prohibition are excluded the sources "marketed for professional uses and which modes for correct use are clearly indicated by the person responsible for placing them on the market".

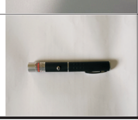
Accordingly, considering the definition of the classes of the IEC, while in the USA an AEL up to 5 mW is allowed, a laser pointer can be freely marketed in Italy only if the AEL is below 1 mW. However, the professional use of laser devices accompanied with instructions given by the supplier has no actual limit of AEL, provided that the exposure limit values set in 2006/25/EU Directive, in Italy Legislative Decree 81/2008, are not exceeded.

It is also important to point out that, in both standards, classification depends on AELs but also on other relevant exposure conditions such as visible or invisible radiation and short pulses emission. In this work, four laser pointers found in different market benches in Italy are characterized considering label data and actual performances, in comparison with safety standards. Different countries can allow different laser classes as shown above, but it should be noticed that classification is not a risk assessment, but only a practical way for the producer to warn about the safe use of a source. The knowledge of the class allows to better assess under which conditions the exposure limit values (ELV) can be respected, the ELVs, anyway, whatever the Standard considered, are derived from the International Commission on Non Ionizing Radiation Protection (ICNIRP), and their guidelines are the scientific consensus supporting international standards. Local regulations may not be promptly updated when ICNIRP guidelines are reviewed, and this must be considered in the design of safety measures. Legal consequences of the marketing of non compliant sources are not considered in this work since it deals with easily available products. A statistical significance cannot be found in this study, since only four devices purchased in three Italian locations were tested; however the same testing procedure is relevant in order to suggest possible procedures for future systematic testing. Moreover, discussing safety aspects of the use of laser pointers by the general public could be helpful in the risk assessment in many workplaces where these devices are in use. This discussion is of particular relevance for those countries, such as Italy, which have not yet developed a legal enforcement for the protection of general public from the risk involved in laser sources.

Material and methods

The laser devices shown in Table 1 were compared from the point of view of available information to the purchaser and the actual performances.

Table 1: List of examined lasers, the pictures have different magnifying; lasers 3 and 4 have the same dimensions

		Colour	*Declared wavelength*	*Declared power*
Laser 1		Red	none	none
Laser 2		Red	650 ± 10 nm	<5 mW
Laser 3		Green	532 ± 10 nm	<5000 mW
Laser 4		Blue	405 ± 10 nm	<5 mW

Lasers 1 and 3 are designed to project patterns obtained by a filter mounted on the laser aperture. In Laser 1 the filter is removed rotating a knob having also the function to switch from different patterns. In Laser 3, no warning label or symbol suggests that it is possible to remove the filter, however neither is present any advice of the fact that the full power is accessible removing the filter and this can be done without any tool or applying a relevant strength. For these reasons, in the following, the four lasers will be compared only when used as pointers, delivering the maximum irradiance in the smallest spot. The divergence θ of the beams were estimated evaluating the spot diameter at laser aperture and at 50 meters distance by the relation:

$$\theta = \left(\frac{d - d_1}{\mathrm{r}} \right) \qquad (1)$$

where
d diameter at laser aperture;
d_1 diameter at 50 m;
r = 50 m.

Considering the uncertainties in the diameter determination, beam divergence can be determined with an estimated accuracy of 50%. An accurate determination of divergence, would have required the d63 measurement by the knife-edge method [Paschotta, 2008] with a power meter and the source mounted on an optical bench, but this is not practical for the scope of this work. Beam power was measured by a Nova II power meter (Ophir Optronics Solutions Ltd Jerusalem, Israel) with a 3A-P-DIF-V thermopile detector. The detector is 10 mm in diameter with ± 5% accuracy and flat wavelength response from 200 to 6000 nm. An aluminium frame with 7 mm diameter hole has been used to partialize the detector in order to evaluate AELs for eye. The wavelength was checked diffusing the beam with a Bruel & Kjaer Type 1100 white sample (Brüel & Kjær Nærum, Denmark) and measuring the diffused spectrum with an Ocean Optics HR4000 spectroradiometer (Ocean Optics Inc., Dunedin, FL - USA). The beam time profile was determined with an ET2000 photodiode (Electro-Optics Technology Inc. Traverse City Mi - USA) connected to a GW Instek GDS-2104 digital storage oscilloscope (Good Will Instrument Co., Ltd. New Taipei City Taiwan).

Results

A first observation is that the power output strongly depends on the charge of the batteries. In Figure 1, the power output of Laser 1 is plotted versus time, starting with a new battery set (disposable button cells). After some hours, the power falls below 1 mW, which is the AEL for class 2 lasers according to IEC. In the following, all power dependent quantities will be referred to the maximum power obtained with fully charged batteries. Values of maximum power measured ad 10 cm from the laser aperture on a target with the diameter of 7 mm, are reported in Table 2. These values are very different from the declared values except for Laser 3 where the statement "<5000 mW" is incorrect since the AEL limit for class IIIb is actually 500 mW.

Table 2: Measured output values

	Total power output @ 100 mm mW	Declared power
Laser 1	1,7 ± 0,1	none
Laser 2	7,1 ± 0,4	<5 mW
Laser 3	58,7 ± 2,9	<5000 mW
Laser 4	36,7 ± 1,8	<5 mW

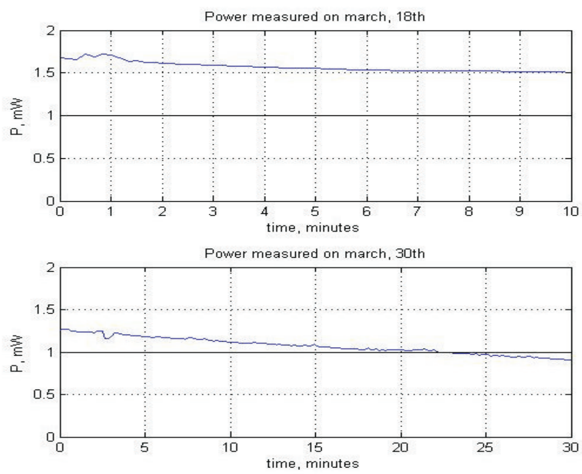


Figure 1: Output power of laser 1 measured in 2010 after replacing batteries

The wavelength of laser devices should be one of the parameters known with the least uncertainty, since laser transition occurs between specific energy levels. This is basically true with some exceptions, mainly represented by the known neodymium-doped yttrium aluminium garnet (Nd:YAG) laser, widely described in literature, which basic emission occurs at 1064 nm. When the electric field of the beam polarizes the traversed medium, a doubling of the wave frequency is achieved with a resulting beam at half of the original wavelength [Paschotta, 2008]. By this way, Nd:YAG lasers are widely used as infrared (IR) sources but they can also be doubled in frequency to obtain 532 nm green light and in some cases even an ultra-violet 266 nm laser source. In most of the applications, unwanted wavelengths are shielded, but Table 2 and Figure 2 show that, while other considered lasers show the typical wavelengths of diode lasers, Laser 3 shows the typical emissions of a so-called "doubled Nd:YAG" laser.

In Figure 2 appears also the 804 nm wavelength of the IR source used to "pump" the 1064 nm main transition. The figure shows that in this device, the IR beam, far to be shielded, delivers the greatest fraction of the total power emitted.

Table 3: Measured wavelengths

	Colour	*Measured Peak wavelengt(s) nm ± 2*	*Declared wavelength*
Laser 1	Red	654	none
Laser 2	Red	656	650 ± 10 nm
Laser 3	Green	532 - 804 - 1064	532 ± 10 nm
Laser 4	Blue	409	405 ± 10 nm

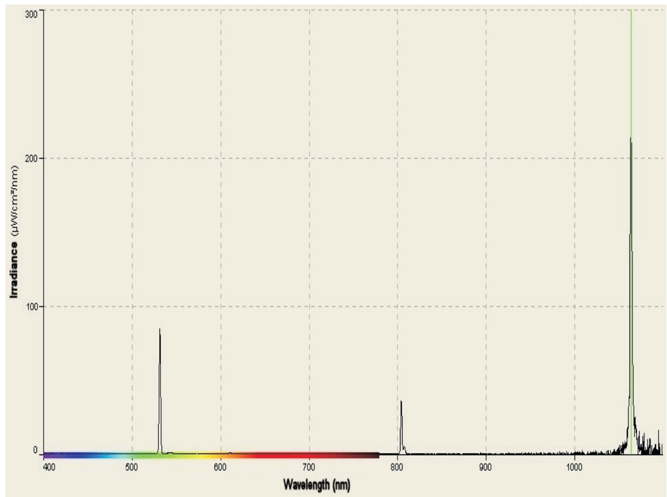


Figure 2: Spectrum of Laser 3 as measured on the spot projected on a white diffuser

By comparing the heights of the main peaks, for laser safety considerations, it can be assumed that the power output of Laser 3, is distributed as follows:

24 % green light 532 nm

76 % IR 1064 nm

For simplicity, the 804 nm, near IR, emission of the pump has been summed to the main 1064 nm beam. This means, that the "useful" power as pointer of Laser 3 is 14 mW, and this is lower than that of Laser 4 even if, from the laser safety point of view, it delivers an higher power.

In Figure 3 another safety issue of Laser 3 is demonstrated: after less than 4 seconds of irradiation, the combustion of the black rubber back of a computer mouse-pad was initiated. This effect has not been observed with other lasers considered and in particular with Laser 4, therefore it can be concluded that IR radiation is responsible for the fast accumulation of heat in rubber, thus enhancing its temperature above the ignition point. The ability of a laser in starting fires is due to the heat absorption properties of the material, at the specific wavelength and irradiance achieved. Higher collimation makes a laser dangerous at a higher distance. From this point of view it was estimated that Lasers 1 and 4 can be considered as having a 2 mrad divergence, while it was estimated that Lasers 2 and 3 have a 1 mrad divergence. The time course analysis of the output made with the photodiode and oscilloscope showed continuous wave (CW) operation for each laser tested.

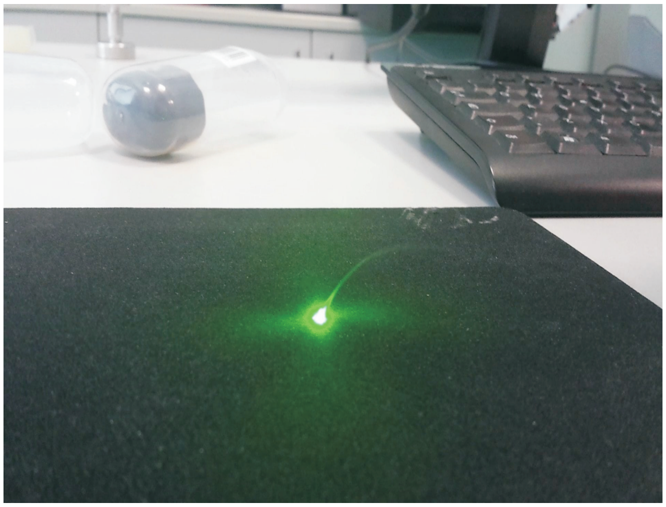


Figure 3: Ignition of rubber after 4 s irradiation with Laser 3

Safety calculations

Table 4 shows clearly that none of the considered lasers complies with the standards, since power is well above what is declared on the labels, when present. In the following, some risk assessment calculation will be shown based on IEC standard Maximum Permissible Energies (MPE), taken as Exposure Limit Values (ELV) by the 2006/25/EU Directive which has the force of law throughout the European Union. The key points of laser risk assessment are the choices of exposure time and viewing distance. Since the light of the four lasers is in the visible range, a direct viewing of the beam will be limited in time by the natural reaction of the eye. In this case, according to the IEC standard, viewing time is limited to 0,25 s. Staring directly into a collimated laser source at close distance, in principle, does not involve the maximum risk since this depends on the retinal image dimension. According to the EU Directive, therefore, the ELV, in J/m² (radiant exposure) is given by:

$$ELV_{vis} = 18 \cdot C_E \cdot t^{0,75} \qquad (2)$$

where C_E is the ratio between the angular subtense of the source and a limit angle of 1,5 mrad. Increasing distance, the angular subtense and, accordingly, C_E is reduced until the retinal image of the source reaches a minimum and $C_E = 1$; for a 5 mm source this happens at 3333 mm.

In Table 4, the radiant exposures for a viewing time of 0,25 s at 100 mm and 3333 mm are compared with the corresponding ELVs; the cases in which the ELV is exceeded are reported in bold. For Laser 3, has been here assumed that all the power falls in the visible range where the ELV is given in (2); actually, in the near infrared, for the same exposure duration, the ELV is higher:

$$ELV_{ir} = 90 \cdot C_A \cdot C_E \cdot t^{0,75} \qquad (3)$$

where C_A = 1 at 1064 nm.

Comparing the heights of the peaks in Figure 2, it is possible to obtain the actual power in each range and divide it by the proper limit; the ELV is respected if the following relation holds:

$$\frac{Hvis}{ELV_{vis}} + \frac{H_{ir}}{ELV_{ir}} < 1 \qquad (4)$$

Table 4: Radiant exposures and applicable ELVs for a 0,25 s viewing, in bold when ELVs are exceed

		ELV @ 100 mm = 212,1 J/m²		*ELV @ 3333 mm = 6,4 J/m² (C_E = 1)*	
	Total power output mW	*Radiant exposure @ 100 mm J/m²*	*% over ELV*	*Radiant exposure @ 333 mm J/m²*	*% over ELV*
Laser 1	1,7	20.0	9%	4,0	62%
Laser 2	7,1	83,3	39%	**16,6**	**259%**
Laser 3	58,7	**691,0**	**326%**	**137,3**	**2145%**
Laser 4	36,7	**432,0**	**204%**	**85,8**	**1341%**

Table 5: Weighted sum of the ELVs for the Laser 3

	Power output mW	*VLE @ 3333 mm J/m²*	*Radiant exposure @ 3333 mm J/m²*	*Weighted sum*
Laser 3 (532 nm)	13.9	6,4	63,7	**1646,5%**
Laser 3 (1064 nm)	44.8	31,8	205,4	

The calculation of this weighted sum is reported in Table 5, showing that even in this less cautionary evaluation, the ELV is exceeded.

Further increasing of the distance does not involve a reduction of the ELV since the retinal image is assumed to have already achieved the minimum diameter, moreover radiant exposure decreases due to the divergence of the beam. The Nominal Ocular Hazard Distance NOHD, is the distance at which the beam widening reduces the radiant exposure below the ELV, it is given by:

$$NOHD = \frac{1}{\theta}\left(\sqrt{\frac{4kP}{\pi \cdot ELV}} - a\right) \qquad (5)$$

If θ is the beam divergence in radians, the ELV is expressed as irradiance in W/m^2, P is beam power in W and a is the source diameter in meters, NOHD results also in meters.
The coefficient k is recommended by the IEC to take into account that the beam could have a non gaussian modal structure, with areas hotter than others in the broadened spot. Figures 3 and 4 suggest that this could be the case at least for Lasers 3 and 4 since the spot appears to be not uniform but the issue should be better studied using a beam profiler. The conclusions of this study are unaffected if $k = 1$ is assumed.

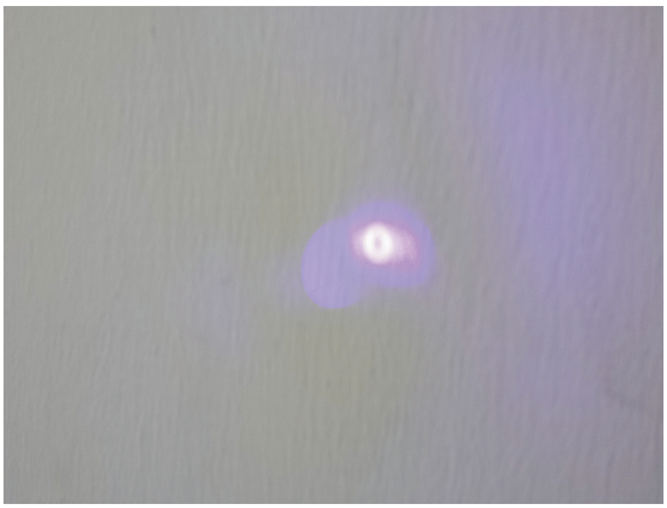


Figure 4: Structure of the broadened spot in laser 4 at 50 cm

In Table 6, nominal Ocular Hazard Distances (NOHD) are reported for each laser. For Laser 3, the calculation was based on the ELV for visible wavelength only, as it is the most restrictive. In the case of Laser 1, for exposure times <0,25 s, the viewing is safe due to the low power with not so low divergence. In fact, American Standard allows the marketing of IIIa (CFR 21) lasers as pointers while in Italy only class 2 (IEC) is allowed.

Table 6: Nominal Ocular Hazard Distance

		ELV @ 3333 mm = 6,4 J/m^2 (C_E=1)		
	Total power output mW	*Irradiance @ 3333 mm W/m^2*	*Nominal Ocular Hazard Distance m*	*Radiant exposure @ 3333 mm J/m^2*
Laser 1	1,7	2,1	-	-
Laser 2	7,1	8,7	**13,8**	16,6
Laser 3	58,7	71,8	**49,0**	137,3
Laser 4	36,7	44,9	**18,9**	85,8

Notice that, beyond the NOHD, the laser can be considered safe from the ocular injury point of view but dazzling effects could still be dangerous if the laser is directed toward aircrafts, for example in landing phase but not only.

Discussion

Actually, considering a point source irradiating a 7 mm spot, the radiant exposure of a 5 mW laser in 0,25 s is 32,5 J/m^2, that's why Italy and other countries [Saunte and Torp-Pedersen, 2015] allow the free marketing only for class 2 (IEC) lasers. In Figure 5 is shown the ELV for a visible laser vs exposure time, compared with radiant exposure generated by a 1 mW laser on a 7 mm spot. If the exposure time does not exceed 0,25 s, the ELV is complied; it is worth to be noticed that, when a laser is used by children, the assumption that this value is true, is far from being proven [Dirani et al., 2013].

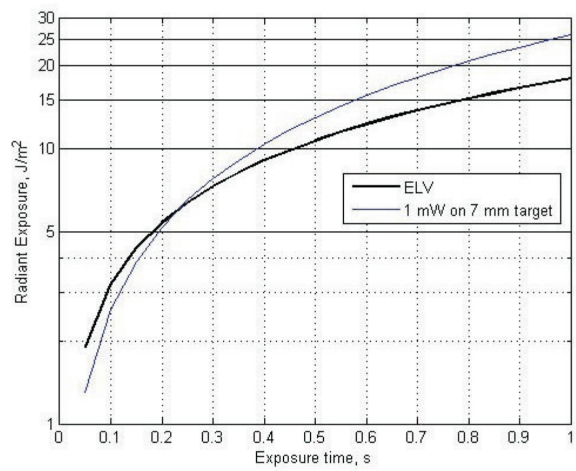


Figure 5: the ELV for visible laser is respected, with 1 mW for exposure shorter than 0,25 s

All examined lasers could be harmful in the use as toys; safety labels, not present in Laser 1, are particularly misleading in the case of Laser 3 since the IR emission is not reported, as shown in Figure 6. From the point of view of possible eye injury, this should not be so relevant since the ELV in near IR is higher than in visible range, the target organ being the retina, however the IR emission increases the possible thermal damage also on lens and cornea and, as shown above, increases the fire risk as well. In a Technical Note of the National Institute of Standards and Technology (NIST) of the United States, the construction and working principles of this kind of pointer is better described [Galang et al., 2010], together with a simple method to detect the presence of the IR emission, without the use of specialized instrumentation.

This method, though not useful for the risk assessment, is worth to be considered for education and training of safety staff. For Lasers 2 and 4, the actual power is simply higher than declared. The comparison of declared and actual power for handheld laser pointers shown above, is not supported by an adequate statistics but it can be considered in accordance with a test conducted in the USA in 2012 [Hadler et al., 2013] which found 90% of non compliance of green laser pointers. Further evidence that the problem has a global dimension and that international regulation is needed, can be achieved comparing the pictures of the lasers in Table 1 with those reported in the quoted references where the shape, labels and aspect of the devices are the same for pointers found in Italy and USA. Actually, 2006/25/EU Directive makes explicit reference to the classification according to IEC, which requires a label like that in Figure 7 that shows the label that should appear on a laser freely marketable as a pointer.

Figure 6: Safety label of Laser 3 does not mention IR emission; the reference to CFR 21 is incorrect

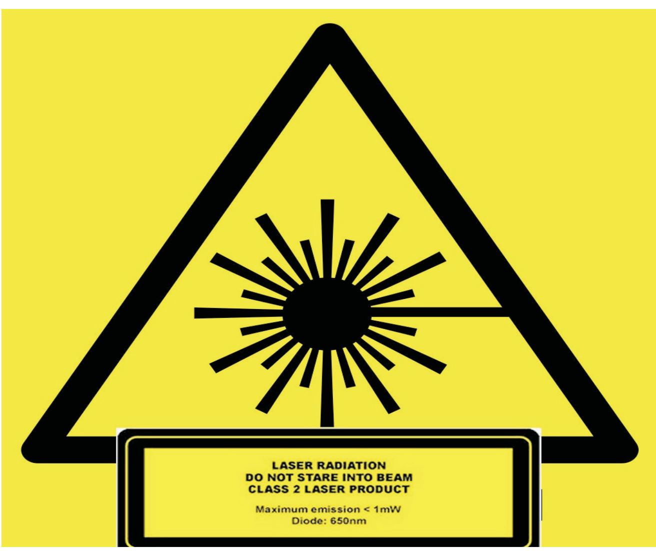


Figure 7: safety label of laser pointer allowed according to Italian law

So far, two different classifications still coexists on the market, and many manufacturers make reference to both in the instruction manuals. Within the European Union, the manufacturers who make reference at least to IEC standard are preferable, of course it still remains to be proven the actual compliance of their products.

Conclusions

All tested devices show accessible energy levels higher than expected and are not compliant to the applicable safety standards. The power level of laser pointers can vary with battery charge; a power test with full charged battery is required in the risk assessment for the use of handheld laser pointer. Special attention is needed with green pointers since they can be based on Nd:YAG lasers doubled in frequency with insufficient shielding of the fundamental 1064 nm emission. Awareness should be diffused among distributors and users concerning the possible eye damages due to misuse of handheld laser pointers, and convergence should be encouraged to a unique classification system, easy to understand throughout the world, allowing the marketing as toys only for eye safe devices. In the risk assessment on the workplaces, the use of handheld laser pointers or other visible lasers should be carefully considered even in presence of classification lower than class 3.

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