PROPOSAL FOR CHANGING THE LASER EXPOSURE LIMITS FOR EXTENDED SOURCE VIEWING

D. Courant[1], D.H. Sliney[2], W. Marshall[2] and L. Court [1,3]

[1] Commissariat à l'Energie Atomique, DSV-DPTE, Bp6, 92265 Fontenay aux Roses France. [2] Laser Microwave Division, US Army Environmental Hygiene Agency, Aberdeen Proving Ground, MD 21010-5422 USA. [3] Centre de Recherches du Service de Santé des Armées, Bp 87, F-38702 La Tronche, France

ABSTRACT

The current laser safety standards have two sets of ocular exposure limits. One set concerns the intrabeam or point source viewing condition, the other a diffuse reflection or an extended laser source. Recent studies of retinal injury thresholds for large retinal image sizes at microsecond exposure times have shown that no safety factor exists in current laser standards for this exposure regime. From a complete review of known biological data, it was possible to develop a set of new exposure criteria that much more closely follow actual injury thresholds. The new proposal makes use of the fact that retinal injury thresholds vary inversely as image size, and limits can be expressed as an angular correction factor to the intrabeam "point-source" exposure limits.

INTRODUCTION

The IRPA and IEC laser safety recommendations have two sets of ocular exposure limits. One set relates to the intrabeam or point source viewing condition, the other to a diffuse reflection or an extended laser source. The latter although seldom used is nevertheless important. The increasing power of lasers can induce hazardous reflections. New laser products, especially in recent investigative techniques of the retina and in retinal imagery, are ever more using extended sources or optics producing large retinal images.

Many biological data exist on damage thresholds for minimal retinal image sizes. No controversy concerning the threshold values has been reported. The experimental results are in good agreement with present exposure limits. At the opposite, for non-minimal images few experiments were performed to know the influence of the retinal image size and specify the corresponding laser injury thresholds. Problems appear when comparing the limit values and the biological data base for large image sizes.

PROBLEMS RAISED BY THE EXPOSURE LIMITS FOR EXTENDED SOURCE VIEWING.

The present exposure limits for viewing extended sources or diffuse reflections of laser radiation are a function of the exposure duration. For extended sources, the exposure limits are usually expressed in $W.cm^{-2}.sr^{-1}$ (radiance) and in $J.cm^{-2}.sr^{-1}$ (integrated radiance). For a given exposure duration, the integrated radiance limit specified at the cornea determines a corresponding retinal radiant exposure limit expressed in

$J.cm^{-2}$. This limit value does not vary with the size of the retinal image. Thus, the corneal exposure limit determines the same invariable radiant exposure limit for every retinal spot size. By example, the retinal radiant exposure corresponding to the exposure limit (EL), is 10 $mJ.cm^{-2}$ for viewing angles as different as 0.004 and 0.033 radian. However, the biological data have shown a dependence of the retinal lesion threshold on image size. What is the maximal image size taken into account by the standard? This is not specified for the present EL.

The use, in the most recent studies, of an investigative technique such as fluorescein angiography, has shown that the retinal damage thresholds are lower than those reported in the early experiments using a direct ophthalmoscopic method [1,2]. The results demonstrated that at the relevant limit value, there is a risk of lesion which can be detected by angiography for retinal spot sizes greater than 250 µm. The risk or probability of detecting a damage is increasing with the retinal image diameter.

THE NEW PROPOSAL

From a complete review of known biological data, it was possible to develop a set of new exposure criteria that much more closely follow actual injury thresholds. The good agreement of the experimental data with the exposure limits for point source or intrabeam viewing can be used to specify in a better way the limits for extended source viewing. The regression lines, fitting the biological data obtained with different image sizes, are divided in two groups which depend on the exposure duration in the same way as the intrabeam viewing exposure limits. The relationship established between the retinal lesion threshold level (ED_{50}) and the retinal image diameter can be described by the relevant equation:

$$Hr = b.r^{m}$$

where Hr is the retinal radiant exposure expressed in $J.cm^{-2}$, r the retinal image diameter expressed in µm, m the slope of the line and b is a constant.The similarity of the slopes of the curves allows one to consider very roughly the spot size dependence as a function that is inversely proportional to the image diameter. The best fit to the data is obtained with slopes m of -0.8 to -1.2. This is corroborated for exposure durations ranging from 10^{-9} s to 10 s [2].

The new proposal makes use of the fact that retinal injury thresholds vary inversely as image size, and limits can be expressed as an angular correction factor to the intrabeam "point-source" ELs. Using this relationship, the retinal radiant exposure corresponding to the limit EL for extended source viewing (H ELes) could be expressed as the corresponding radiant exposure for the point source limit value (H ELps) multiplied by a correction factor CF that includes an image size dependent term:

New H ELes (for extended source) = H ELps (for point source) x CF

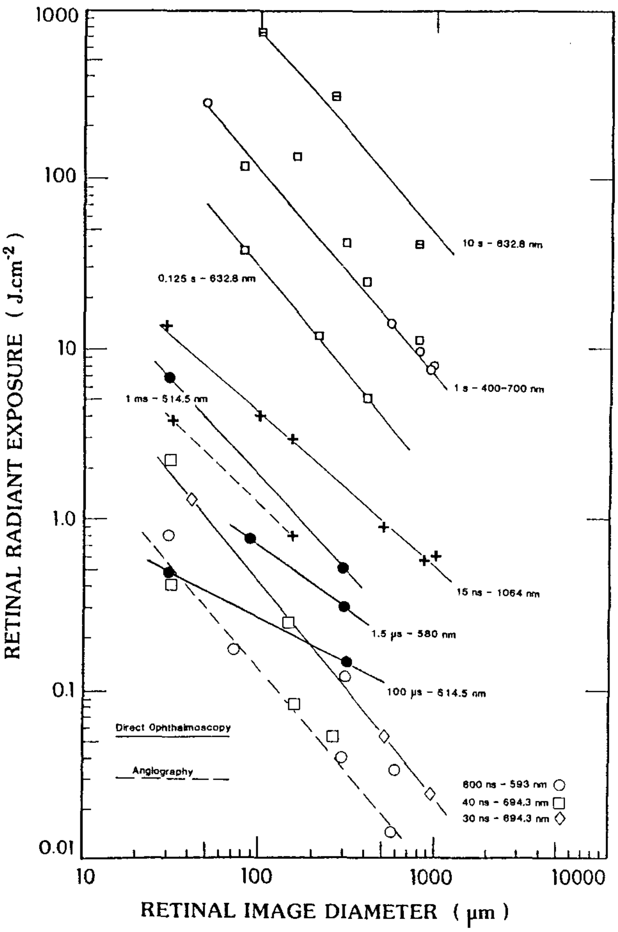

Figure 1. The relationship between the retinal damage threshold (ED_{50}) and the retinal spot-size.

The multiplicative correction factor CF can be expressed as follows:

$$CF = (\alpha / \alpha_{min})^{m}$$

where α is the angular subtense or visual angle of the extended source and α_{min} the limiting angle which determines extended source versus point source viewing condition. The value of the slope *m* is choosen 1.0. In the standard, α_{min} varies with the exposure duration, whereas in our proposal α_{min} is a fixed value in the thermal injury domain. It may be convenient to consider a value of α_{min} equal to the lowest effective retinal image size formed on the retina but it may be too possible to choose a larger value of α_{min}, at which the experimental data still warrant the exposure limits.

For exposure durations larger than 10 s, the effects of eye movements become dominant on the retinal spot-size. A good value for α_{min}, based upon eye movements recordings for fixating a point seems 11 milliradians. A transition value of α_{min} should be defined for exposure ranging from 1-3 s, when the eye movements begin to influence the retinal image diameter, to 10 s.

The recent thermal model calculations show that the 1/r spot-size dependance ends at about 1-2 mm retinal image diameter. Hence, a single radiance limit is possible for visual angle subtending the source corresponding to retinal image diameters larger than 1-2 mm. The visual angle specifying the use of a radiance limit could be defined by the new term α_{max}.

This formulation allows one to specify safety margins for large image diameters equivalent to those existing for intrabeam viewing conditions. This revision effort also has implications for exposure limits applied to non-coherent light sources.

REFERENCES

1. Courant D., Court L., Abadie B. and Brouillet B., 1989, Retinal damage thresholds from single pulse laser exposures in the visible spectrum, Health phys., 56, pp. 637-642.

2. Courant D., Court L. and Sliney D.H., 1989, Spot-size dependence of laser retinal dosimetry in Dosimetry of Laser Radiation in Medicine and Biology, GJ Müller and DH Sliney eds. published by SPIE Optical Engineering Press, Washington, 156-165.

3. Ham W.T. and Mueller H.A., 1987 , . Applied optics, 26, pp. 3456-3460.

4. Delori F.C.,Parker J.S. and Mainster M.A., 1980, Light levels in fundus photography and fluorescein angiography. Vision Res., 20, pp. 1099-1104.