Eyesafe laser rangefinders

B.Sc. Snir Mordechai, Ph.D. Margaliot Menachem, M.Sc. Arie Amitzi

1 Snir Mordechai, B.Sc. Physicist and LSO in El-Op, Israel.
2 Margaliot Menachem, Ph.D. and Amitzi Arie, M.Sc. Radiation Safety Department, Soreq NRC, Yavne 81800, Israel.

Abstract
During the 1970's, Ruby (Q switched) laser based rangefinders with a wavelength of 694nm were first used. These lasers operated in a pulse mode within the visible light range and produced a risk for the eye retina. The laser beam striking the macula could damage the eye and might cause blindness. Over the years, Nd:YAG (Q switched) lasers were developed (operating at 1064nm) for rangefinding and designation uses.

The wavelength of these lasers, operating in the near Infra-Red range (invisible), is also focused tightly on the retina. The human eye does not respond to the invisible light so there is no natural protection (eye blink reflex) as in the visible light.

The operation of these lasers worldwide, especially when the laser beam is exposed, causes occasional eye accidents. Another risk is stemming from the use of observation systems with a high optical gain, in the laser operation areas, which enlarge the range of risk quite significantly. Therefore, research and development efforts were invested in order to introduce eyesafe lasers. One of the solutions for this problem is presented in following document.

1. Applicable solution
Since the 90's, Erbium:Glass laser is the main technology used for eyesafe laser rangefinders and other applications as well. This laser is emitting in 1540nm, which is beyond the retinal hazard band (1).

The Nd:YAG laser has four energy levels that provide it with advantages over the Erbium:Glass laser, which has only three energy levels. However, it is emitting in 1064nm, and cause most of the accidents involving retinal damage (2). The low thermal conductivity of Erbium:Glass is a key limiting factor for laser operation at high repetition rates. Using Diode Pumped Erbium:Glass laser technology, has reduced the thermal problem.

Safety range analysis was performed according to the following specifications: International Electro-technical Commission 60825-1 Safety of Laser products(3). The calculations were performed according to the following data:

1) Erbium:Glass laser, Wavelength 1540nm.
2) Energy per pulse - 10mJ.
3) Pulse Repetition Rate - 10pps
4) Pulse width - 30nsec.
5) Beam shape – Gaussian
6) Beam diameter – 4.2mm (1/e)
7) Laser beam geometries display transverse electromagnetic – TEM00.
2. IEC Laser Classification

Since we analyzed a pulse repetition frequency laser for ocular exposure, for wavelengths between 400nm and 10⁶, we assessed the following three criteria:

a. Single pulse assessment
b. Average irradiance assessment
c. Multiple pulse assessment

The MPE (Maximum Permissible Exposure) will be the lowest number among the three criteria.

<table>
<thead>
<tr>
<th>Class</th>
<th>Single pulse AEL</th>
<th>^{(1)} Repetitive pulse AEL</th>
<th>Average Power AEL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class 1</td>
<td>8 mJ</td>
<td>2.53 mJ</td>
<td>10 mW</td>
</tr>
<tr>
<td>Class 3R</td>
<td>40 mJ</td>
<td>12.6 mJ</td>
<td>50 mW</td>
</tr>
<tr>
<td>Class 3B</td>
<td>125 mJ</td>
<td>39.5 mJ</td>
<td>500 mW</td>
</tr>
</tbody>
</table>

The laser will be classified according to the AEL (Accessible Emission Limit) by calculating the output energy or power (Pₐ) passing through the appropriate limiting aperture using the following equation:

\[
P_a = P_0 \left[ 1 - \exp\left(-\left(\frac{d_a}{d_{63}}\right)^2\right) \right]
\]

where:
- \(P_0\) - the total output laser energy.
- \(d_a\) – the limiting aperture diameter.
- \(d_{63}\) – the beam diameter at the 1/e point.

### 2.1 Rule 1. Single pulse limit:
- \(d_a = 1\) mm, the limiting aperture for time less than 0.35 seconds of laser pulse duration (table 7 in the STD – p. 54).
- \(P_0 = 10\) mJ.
- \(d_{63} = 1.95\) mm

Therefore \(P_a = 2.3\) mJ. As \(P_a < 8\) mJ, the laser should be classified as **Class 1**

### 2.2 Rule 2. Average Power Limit
- \(d_a = 3.5\) mm, the limiting aperture for up to 10 seconds of laser emission duration (table 7 in the STD – p. 54).
- \(P_0 = 100\) mW, the total output energy during 10 seconds is 1000mJ so the average power is 100mW.
- \(d_{63} = 1.95\) mm

Therefore \(P_a = 96\) mW. As \(P_a > 50\) mW but \(< 500\) mW the laser should be classified as **Class 3B**

### 2.3 Repetitive Pulse Limit
- \(d_a = 1\) mm, the limiting aperture for up to 0.35 seconds of laser pulse duration (table 7 in the STD – p.54).
- \(P_0 = 10\) mJ.
- \(d_{63} = 1.95\) mm
Therefore $P_a = 2.3 \text{ mJ}$. As $P_a < 2.53 \text{ mJ}$, the laser should be classified as Class 1

2.4 Summary
According to rule no. 2, the analyzed laser is a Class 3B laser.

3. Nominal ocular hazard distance (NOHD) calculation
To maintain safety at any range of direct intrabeam viewing, the laser output power or energy density shall be below the MPE level (Maximum Permissible Exposure). The MPE for Eye Hazard Analysis is the most restrictive MPE of the three rules. The values for those MPE’s are as following (table 6 in the IEC STD):

- Single pulse MPE value = 1 J/cm²
- Average Power MPE value = 100 mW/cm² = 0.1 W/cm²
- Repetitive-pulse MPE value = $\text{MPE}_{\text{single}} \times N^{-0.25} = 0.316 \text{ J/cm}^2$

Thus, the most restrictive MPE value is $0.1 \text{ W/cm}^2$

$$r_{\text{NOHD}} = \frac{1}{\phi} \left[ \sqrt{\frac{4P}{\pi \text{MPE}}} - a \right]$$

$P = 0.1 \text{ W}$
$\text{MPE} = 0.1 \text{ W/cm}^2$
$\phi = 2.9 \text{ mRad}$
$a = \text{Beam Diameter \ 0.42cm}$

According to the NOHD equation, the RF-10DP laser will be safe for direct intrabeam viewing only from ranges longer than 244 cm.

4. Reducing the laser classification from Class 3B to Class 1M
Class 3B laser is not eyesafe. In order to make it eyesafe, it is necessary to reduce the irradiance, by expending the beam diameter. We can see in equation no. 2, that using a beam expander, with a diameter of above 12 mm, the laser will be safe at zero range. This is correct if no collecting optics is used. Using collecting optics, e.g. 7x50 binocular, reduces the MPE by a factor of 51, and the laser will not be eyesafe.

According to the IEC 60825-1 (3), such a laser is classified as Class 1M.

5. Conclusions
To gain an eyesafe laser rangefinder, it requires:
- Shifting the laser wavelength from the retinal hazard band into a non retinal-hazard band.
- Increasing efficiency of the detector and working with an atmospheric transmission band that allows low laser transmitter.
- Using a beam expander in order to reduce the laser irradiance.

References