A special study of optical radiation hazards was performed on two light detection and ranging system lasers. Both lasers were Class IV high power lasers. The protection standard for intrabeam viewing could be exceeded out to a range of 9.9 km for the ruby laser and 210 m for the CO₂ laser.
1. AUTHORITY.
   b. Letter, DRSEL-NV-SE, Night Vision Laboratory, 1 February 1977,
      subject: Laser Safety, and indorsements thereto.

2. REFERENCES.
   a. AR 40-46, Control of Health Hazards from Lasers and Other High
      Intensity Optical Sources, 6 February 1974.
   b. TB MED 279, Control of Hazards to Health from Laser Radiation,
      30 May 1975.

3. PURPOSE. To evaluate the potential hazards associated with the use of
   the light detection and ranging (LIDAR) system lasers and to make
   recommendations designed to limit exposure of personnel to potentially
   hazardous radiation from these devices.

4. GENERAL.
   a. Background. The Stanford Research Institute (SRI) Mark IX ruby and
      CO2 LIDAR system is used in experiments to take simultaneous multispectral
      transmissometer measurements and backscatter measurements to explore the
      relationships between propagation and the physical microstructure of the
      atmospheric aerosol during conditions of fog, rain, snow and military smoke.
      The system employs two lasers: one which operates in the visible, the ruby
      laser; and another vehicle operates in the far infrared, the CO2 laser used
      to test effects at the far infrared laser wavelengths. Personnel of the US
      Army Environmental Hygiene Agency performed measurements of the LIDAR Mark IX
      system at Dugway Proving Ground, UT on 22 September 1977.
   b. Inventory. Only one LIDAR Mark IX system had been constructed at the
      time of the study.
   c. Instrumentation.
      (1) EG&G Model 580 Radiometer System with Type 23A detector head.

Approved for public release; distribution unlimited
Nonionizing Radn Prot Sp Study No. 42-0331-78, 22 Sep 77

(2) Laser Precision Corp. Model RK 3230 energy meter with Type R108-2B
detector head.

(3) Scientech Model 364 power energy meter with Scientech discolorimeter
Model 360401.

d. Abbreviations. A table of commonly used radiometric terms and units
is provided in the appendix.

5. FINDINGS.

a. Laser Output Parameters for Ruby System.

(1) Wavelength: 694.3 nm
(2) Radiant Energy: 1.0 J/pulse (specified) 0.5 J/pulse (measured)
(3) Emergent Beam Diameter: 2.0 cm
(4) Pulse Width: 30 ns
(5) Pulse Repetition Frequency (PRF): 1 Hz
(6) Beam Divergence: 0.5 mrad (focused), 1.8 mrad (unfocused)

b. Laser Output Parameters for CO2 System. This system uses a Luminics
TEA-101-2 Laser.

(1) Wavelength: 2.5 to 11 μm (used at 10.6 μm)
(2) Radiant Energy: 5.0 J/pulse (maximum), 0.7 J/pulse (measured)
(3) Beam Divergence: 1.2 mrad (focused), 2.3 mrad (unfocused)
(4) Pulse Width: 0.05 to 50 ns
(5) PRF: 1 Hz
(6) Emergent Beam Diameter: 2.5 cm

c. Beam Characteristics as a Function of Range. The protection standard
(PS) for intrabeam viewing of a single pulse for the ruby laser is 0.5 μJ/cm²
and for the CO2 laser it is 10 μJ/cm². Beam radiant exposure measurements
were taken at 1.0 km for both lasers; a reading of 12 μJ/cm²/pulse was
obtained for the ruby laser and 20 μJ/cm²/pulse was obtained for the CO2
laser. A theoretical plot of irradiance vs range with measured and
theoretical values is provided in the Figure.
Nonionizing Radn Prot Sp Study No. 42-0331-78, 22 Sep 77

Developer's Specification for CO$_2$ Laser
Q = 5.0 J
$\phi$ = 1.2 mrad
$\alpha$ = 2.5 cm$^{-1}$
$\mu$ = 10$^{-7}$ cm$^{-1}$

for Ruby Laser
Q = 1.0 J
$\phi$ = 0.5 mrad
$\alpha$ = 2.0 cm$^{-1}$
$\mu$ = 10$^{-7}$ cm$^{-1}$

Measured Values for CO$_2$ Laser
Q = 5.0 J
$\phi$ = 2.3 mrad
$\alpha$ = 2.5 cm$^{-1}$
$\mu$ = 10$^{-7}$ cm$^{-1}$

for Ruby Laser
Q = 1.0 J
$\phi$ = 1.8 mrad
$\alpha$ = 2.0 cm$^{-1}$
$\mu$ = 10$^{-7}$ cm$^{-1}$

Ruby laser
P.S. for single pulse exposure (500 nJ/cm$^2$)

FIGURE 1. RADIANT EXPOSURE AS A FUNCTION OF RANGE FOR THE RUBY AND CO$_2$ LASER
d. Warning Label. A warning label was permanently attached to the CO₂ laser transmitter and read: Danger, invisible laser radiation. Avoid eye or skin exposure to direct or scattered radiation. The ruby laser had a warning label which read: Danger, Laser Light.

6. DISCUSSION.

a. Hazard Classification. Both lasers considered in this study emitted optical radiation in excess of the upper limits for Class III lasers hence both are Class IV high power lasers in accordance with Table B-2, Appendix B, TB MED 279.

b. Optical Viewing Instruments. Viewing the direct beam with magnifying optics may increase the corneal radiant exposure by as much as the square of the magnifying power of the optical device for the ruby laser, while viewing the CO₂ laser through optics will actually attenuate the beam coming through the optics.

7. CONCLUSION. Both lasers emit optical radiation which exceed current protection standards. These devices may be operated safely, however, provided appropriate precautions are taken.

8. RECOMMENDATIONS. Maintain adequate communication between operator and personnel downrange at all times when either laser is being operated (paragraph 5-31, AR 40-5).

a. Ruby Laser.

(1) Do not permit unprotected personnel in the beam path out to a distance of 9.9 km from the laser transmitter (paragraph 5-31, AR 40-5).

(2) Provide eye protection with an optical density of 6.3 or greater at 694.3 nm for personnel downrange within the nominal hazardous distance of the laser [paragraph 1-5d(3), AR 40-46].

b. CO₂ Laser.

(1) Do not permit unprotected personnel in the beam path out to a distance of 110 m (focused) or 210 m (unfocused) from the laser transmitter (paragraph 5-31, AR 40-5).
Nonionizing Radn Prot Sp Study No. 42-0331-78, 22 Sep 77

(2) Provide eye protection with an optical density of 2.7 or greater at far infrared (2.5 to 11.0 μm) for personnel downrange within the nominal hazardous distance.

PEDRO F. DEL VALLE
ILT, MSC
Nuclear Medical Science Officer
Laser Microwave Division

DARIUS J. CREWS
Laboratory Technician
Laser Microwave Division

APPROVED:

GARY W. GASTON
MAJ, MSC
Chief, Laser Microwave Division
### Table II

**USERPIL CII Radiometric and Photometric Terms and Units**

<table>
<thead>
<tr>
<th>Term</th>
<th>Symbol</th>
<th>Defining Equation</th>
<th>SI Unit and Abbreviation</th>
<th>Term</th>
<th>Symbol</th>
<th>Defining Equation</th>
<th>SI Unit and Abbreviation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Radiant Energy</td>
<td>$E_o$</td>
<td>$dE_o$</td>
<td>Joule (J)</td>
<td>Quantity of Light</td>
<td>$Q_v$</td>
<td>$\int dQ_v$</td>
<td>lumen-second (lm·s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>(talbot)</td>
</tr>
<tr>
<td>Radiant Energy Density</td>
<td>$W_v$</td>
<td>$\frac{dW_v}{dV}$</td>
<td>Joule per cubic meter (J·m⁻³)</td>
<td>Luminous Energy Density</td>
<td>$W_v$</td>
<td>$\frac{dW_v}{dV}$</td>
<td>talbot per square meter (lm·s·m⁻²)</td>
</tr>
<tr>
<td>Radiant Flux (Radiant Flux)</td>
<td>$P_v$</td>
<td>$\frac{dP_v}{dt}$</td>
<td>Watt (W)</td>
<td>Luminous Flux</td>
<td>$P_v$</td>
<td>$\int dP_v \theta \lambda d\lambda$</td>
<td>lumen (lm)</td>
</tr>
<tr>
<td>Radiant Intensity</td>
<td>$I_v$</td>
<td>$\frac{dI_v}{d\Omega}$</td>
<td>Watt per steradian (W sr⁻¹)</td>
<td>Luminous Intensity (candela)</td>
<td>$I_v$</td>
<td>$\frac{dI_v}{d\lambda}$</td>
<td>lumen per steradian (lm·sr) or candela (cd)</td>
</tr>
<tr>
<td>Radiance</td>
<td>$L_v$</td>
<td>$\frac{dL_v}{d\Omega}$</td>
<td>Watt per steradian and per square meter (W sr⁻¹ m⁻²)</td>
<td>Luminance</td>
<td>$L_v$</td>
<td>$\frac{dL_v}{d\lambda} d\Omega$</td>
<td>candela per square meter (cd·m⁻¹)</td>
</tr>
<tr>
<td>Radiant Exposure (Dose, in Photobiology)</td>
<td>$H_v$</td>
<td>$\frac{dH_v}{dA}$</td>
<td>Joule per square meter (J·m⁻²)</td>
<td>Light Exposure</td>
<td>$H_v$</td>
<td>$\int E_v d\Omega$</td>
<td>lux-second (lx·s)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiant Efficiency (of a source)</td>
<td>$\eta_v$</td>
<td>$\frac{P_v}{F}$</td>
<td>unitless</td>
<td>Luminous Efficacy (of radiation)</td>
<td>$K$</td>
<td>$\frac{E_v}{\phi_v}$</td>
<td>lumen per watt (lm·W⁻¹)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Radiant Efficiency (of a source)</td>
<td>$\eta_v$</td>
<td>$\frac{P_v}{F_i}$</td>
<td>unitless</td>
<td>Luminous Efficacy (of a broad band radiation)</td>
<td>$V(\lambda)$</td>
<td>$K \frac{K}{\lambda_\lambda}$</td>
<td>unitless</td>
</tr>
<tr>
<td>Optical Density</td>
<td>$D_v$</td>
<td>$P_v - \log_{10} \lambda_\lambda$</td>
<td>unitless</td>
<td>Luminous Efficacy (of a source)</td>
<td>$\eta_v$</td>
<td>$\frac{P_v}{F_i}$</td>
<td>lumen per watt (lm·W⁻¹)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1. The units may be altered to refer to narrow spectral bands in which case the term is preceded by the word 'per', and the unit is then per wavelength interval and the symbol has a subscript $\lambda$. For example spectral irradiance $H_v$ has units of W·m⁻²·λ⁻¹ or more often, W·cm⁻²·μm⁻¹.

2. While the meter is the preferred unit of length, the centimeter is still the most commonly used unit of length for many of the above terms and the mm or μm are most commonly used to express wavelength.

---

1. $P_i$ is electrical input power in watts. $\theta$ is the transmission.

2. At the source $I = \int dI_v$ and at a receptor $I = \frac{1}{4\pi} \int dI_v$.

3. $I_v$ is retinal illuminance in Trolands (td)·m⁻²·luminance in cd·m⁻²·times pupil area in mm².