Laser Safety Overview

Laser Safety
  Accidents
  Hazards
  Controls
Laser Accidents & Incidents: Overview from one 1999 Survey

- Top 5 lasers: Nd:YAG, Ar, CO₂, dye, diode
- Breakdown of incidents
  - 71% - eye injury
  - 11.9% - skin injury
  - 16.9% - non-beam incident

Data from Rockwell, RJ, ILSC 99 Proceedings, LIA

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Laser Accidents: Personnel Exposure Summary

Accident Data Summary: Division of 395 events: 1964-1998

- Technicians Exposed (81): 20.5%
- Scientists Exposed (78): 19.8%
- Students Exposed (46): 11.6%
- Patients Exposed (40): 10.1%
- Plant Workers Exposed (35): 8.9%
- Dr.s & Nurses Exposed (26): 6.6%
- Pilots & Military Exposed (26): 6.6%
- Spectators Exposed (25): 6.3%
- Laser Show Operators Exposed (11): 2.8%
- Equipment only damaged (10): 2.5%
- Field Service Exposed (10): 2.5%
- Office Staff (uninvolved) (7): 1.8%

Data from Rockwell, RJ, ILSC 99 Proceedings, LIA
Laser Accidents

Eye Injury

>70% of all incidents
Retinal hemorrhage from Q-switched laser pulse.
Visual Effect: Blind spot in field of vision.

Laser Accidents: Research & Development Laboratory

- Most eye injuries have occurred in research and engineering laboratories. Why?
- Open beams
  - During alignment
  - For flexibility in calibration procedures
  - Experimental changes in setup
- “I know where the beam is!” (Famous last words)
Many laboratory accidents result from unexpected upward reflections

Laser Accidents

- Cause of accidents
  - Not using eyewear (may have been available)
  - Incorrect eyewear selection and/or eyewear failure.
  - Improper fit
Laser Accidents:
Most Hazardous Acts – Beam Alignment

- Estimates
  - ~1/3 of all (known) accidents
  - ~60-70% of all (known) laboratory accidents

- Common scenario:
  unanticipated reflection from an optic while not wearing protective eyewear

Laser Accidents:
Most Hazardous Acts – Beam Alignment

- Optics or devices involved in reflections of errant / stray beams:
  - Prisms, Brewster windows, frequency doubling crystals, blade, color center crystal, chrome objective, polarizers, dye cell windows
  - Targets: chalk, photographic paper, test paper
  - Energy meter detector window
Laser Accidents:

Most Hazardous Acts – Beam Alignment

- Not wearing any protective eyewear
- Wearing inappropriate eyewear
  - Wrong OD
  - Wearing low-OD alignment eyewear with operational power levels
  - Wearing high-OD operational eyewear with low-power (alignment) power levels
- Wavelength compatibility problem, especially for multiple wavelengths

Laser Accidents:

Incident at DOE Laboratory

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Figure 2.8: A diagram of the experimental system setup, showing the beam path along the L1 axis, through the target chamber, and out the chamber’s rear window.
Laser Accidents:
Incident at DOE Laboratory

4 primary common causes identified
- Weaknesses in training and a lack of compliance with accepted national standards
- Lack of authority of the LSO
- Inadequate line management oversight of laser operations
- Lack of enforcement of the PPE requirement
  - Failure to wear laser eye protection

Figure 2.10. A team member demonstrates S1’s position when she looked into the target chamber on July 14.

Figure 3.1. IR image of the transmitted laser pulse image on the back wall.
Learning from Laser Accidents

- In most cases, there is a heightened interest in laser safety after a colleague is injured.

- But not always…

Laser Hazards Breakdown

- Laser Hazards
  - Beam Hazards
    - MPE, NHZ
  - Non-Beam Hazards
Beam Hazards:
Optical Concentration by the Eye

- For wavelengths that reach the retina (400-1400 nm, “the Retinal Hazard Region”), the optical concentration is ~100,000 times
- An initial irradiance of 1 W/cm², becomes 100 kW/cm² at retina!

Eye Anatomy

iris
pupil
sclera
Sclera
Iris
Cornea
Pupil
Lens
Conjunctiva
Vitreous
Choroid
Optic nerve
Macula
Retina
**Ocular Absorption Site vs. Wavelength:**

*UV-B, UV-C, IR-B and IR-C*

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**Beam Hazards**

*Corneal Thermal Burns*

Corneal Thermal Injury - Produced by IR-B and IR-C radiation.
Beam Hazards

Corneal Thermal Burn

Superficial Injury -
Epithelium repairs itself
quickly and lesion clears
within one or two days.

Deep Burns - Penetrating
burns produce a permanent
opacity and may require
corneal transplant for repair.
The Lens

- Lens - Provides accommodation, the ability to focus on near objects;
- very slow metabolic rate and limited ability to repair injury;
- becomes less pliable with age, resulting in presbyopia;
- becomes cloudier with age and eventually opacifies, i.e., a cataract is formed.
Cataract

Opacification of the Lens
- clouding of the lens

- Ultraviolet Action
  Spectrum - Ultraviolet at 300 nm (UV-B).
- Infrared (770-3000nm)
- Cataract - Industrial heat cataract common in glassblowers and foundry men at turn-of-the-century.
- Requires many years of exposure to excessive infrared radiant energy.
Ocular Absorption Site vs. Wavelength:
the retinal-hazard region, Visible and IR-A (400-1400 nm)
Beam Hazards

The Retina

- Macula Lutea - (“yellow spot”) where visual acuity is highest and color vision is best.
- Fovea Centralis - Central-most area of macula. Highest concentration of cones. Night blind in this area. Line of optic axis.
- Peripheral Retina - High concentration of rods; region sensitive to movement detection.

[Image of the retina with labels for Macula, Fovea Centralis, and Peripheral Retina]
Beam Hazards
Maximum Permissible Exposure (MPE)

Definition
- Maximum level of exposure to laser radiation without hazardous effect or adverse biological changes in the eye or skin

Used to determine
- Nominal hazard zone (NHZ)
- Optical density (OD)
- Accessible Emission Limit (AEL)

MPEs are generally found in Table 5a, page 74 of ANSI Z136.1 (2007).

MPEs for skin exposures are found in Table 7, page 77 of ANSI Z136.1 (2007).
# Maximum Permissible Exposure (MPE)

**Summary of Five MPE Examples for CW Lasers**

<table>
<thead>
<tr>
<th>Laser Type</th>
<th>Eye or Skin</th>
<th>MPE [W/cm²]</th>
<th>Exposure Duration</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>Eye</td>
<td>0.100</td>
<td>10 s or longer</td>
</tr>
<tr>
<td>Visible</td>
<td>Eye</td>
<td>0.00255</td>
<td>0.25 s</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>Eye</td>
<td>0.0050</td>
<td>10 s or longer</td>
</tr>
<tr>
<td>CO₂</td>
<td>Skin</td>
<td>0.100</td>
<td>10 s or longer</td>
</tr>
<tr>
<td>Nd:YAG</td>
<td>Skin</td>
<td>1.00</td>
<td>10 s or longer</td>
</tr>
</tbody>
</table>

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**Beam Hazards**

**The Nominal Hazard Zone (NHZ)**

- The NHZ is the space within which the level of direct, reflected or scattered laser light exceeds the MPE level for the laser.
### The Nominal Hazard Zone, NHZ:
Laser Criteria Used for NHZ Calculations

<table>
<thead>
<tr>
<th>Laser Parameter</th>
<th>Nd:YAG</th>
<th>CO₂</th>
<th>Argon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wavelength, λ, (µm)</td>
<td>1.064</td>
<td>10.6</td>
<td>0.514</td>
</tr>
<tr>
<td>Beam Power, Φ, (W)</td>
<td>100</td>
<td>500</td>
<td>5.0</td>
</tr>
<tr>
<td>Beam Divergence, φ, (mrad)</td>
<td>2.0</td>
<td>2.0</td>
<td>1.0</td>
</tr>
<tr>
<td>Beam Size at Aperture, a, (mm)</td>
<td>2.0</td>
<td>20.0</td>
<td>2.0</td>
</tr>
<tr>
<td>Beam Size at Lens, b, (mm)</td>
<td>6.3</td>
<td>30.0</td>
<td>3.0</td>
</tr>
<tr>
<td>Lens Focal Length, f₀, (mm)</td>
<td>25.4</td>
<td>200</td>
<td>200</td>
</tr>
<tr>
<td>MPE, 8 hr (Wcm⁻²)</td>
<td>5 x 10⁻³</td>
<td>0.1</td>
<td>1 x 10⁻³</td>
</tr>
<tr>
<td>MPE, 10s (Wcm⁻²)</td>
<td>5 x 10⁻³</td>
<td>0.1</td>
<td></td>
</tr>
<tr>
<td>MPE, 0.25s (Wcm⁻²)</td>
<td>_____</td>
<td>_____</td>
<td>2.5 x 10⁻³</td>
</tr>
</tbody>
</table>

### The Nominal Hazard Zone, NHZ:
Nominal Hazard Zones (NHZ) for Various Lasers

<table>
<thead>
<tr>
<th>Laser Type</th>
<th>Exposure Duration</th>
<th>Direct</th>
<th>Lens-on Laser</th>
<th>Diffuse</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nd:YAG</td>
<td>10 s</td>
<td>790</td>
<td>6.4</td>
<td>0.8</td>
</tr>
<tr>
<td>CO₂</td>
<td>10 s</td>
<td>399</td>
<td>5.3</td>
<td>0.4</td>
</tr>
<tr>
<td>Argon</td>
<td>0.25 s</td>
<td>505</td>
<td>33.6</td>
<td>0.25</td>
</tr>
</tbody>
</table>
Non-Beam Hazards & Z136.1

“Non-beam Hazards” section provides guidance on:
- Electrical hazards (Sec. 7.2.1)
- Collateral and plasma radiation (Sec. 7.2.2)
- Fire hazards (Sec. 7.2.3)
- Explosion hazards (Sec. 7.2.4)
- Mechanical hazards associated with robotics (Sec. 7.2.5)
- Noise (Sec 7.2.6)
- Laser generated airborne contaminants (Sec. 7.3.1)
- Compressed gases (Sec. 7.3.2)
- Laser dyes and solvents (Sec. 7.3.3)
- Assist gases (Sec 7.3.4)
- Biological agents (Sec. 7.4)
- Human factors (Sec. 7.5)

Non-Beam Hazards: Electrical

- Shock
- Electrocution
- Electrically generated fires
  - Not unique to lasers
  - Electrocution: 5th leading cause of work related injury/death in U.S.
  - Electrocution: cause of at least 10 laser-related death
  - 2nd most often reported cause of laser accidents
Non-Beam Hazards
Laser Generated Air Contaminants (LGAC)

- Generated when class 3b or 4 laser beams interact with matter
- LGAC depends upon target material, cover gas and beam irradiance
- Difficult to predict what LGAC is released into air

Non-Beam Hazards
Laser Generated Air Contaminants (LGAC)

- When target irradiance reaches $10^7 \text{ W cm}^{-2}$
  - Target materials may liberate carcinogenic, toxic and noxious airborne contaminants
- LGAC released may be gaseous or particulate
- LSOs responsibility to ensure that any IH issue be addressed and he/she may consult with Industrial Hygienist
Non-Beam Hazards: Compressed Gas

- Rapid release may propel tank
- “low” concentration in tank may produce high concentration in air
- Release of “non-toxic” gases may produce asphyxia due to oxygen displacement

Control Measures: Enclosed Beam Path

- Tubular, anodized aluminum beam tubes provide rigid mounting
- Here, encloses beam from laser into beam bender then to regenerative amplifier.
Control Measures: Enclosed Beam Path

- Use of closed-circuit TV (CCTV) to view micro-material processing application

- Processing occurs in chamber beneath laser; access door is interlocked to laser

Control Measures: Beam Block

Vertical Beam Block
Control Measures: Beam Stop

Confines the beam to the edge of the table using a metal barrier.

Control Measures

EYE PROTECTION

- Wavelength compatibility
- Attenuation at that Wavelength
- Visual Transmittance
- Comfort and Fit
- Training
- Inspection
- Storage
Control Measures
Wavelength Compatibility

- Visible beam was transmitted through lens and damaged carbon paper
- IR-C beam was absorbed by and damaged plastic lens, while carbon paper is intact

Control Measures
Optical Density

Eyewear must be marked with OD as a function of wavelength
Control Measures
Electrical Hazards Controls – Work Practices

- Work on deenergized parts of electrical systems
- Use insulated tools
- Use insulating blankets & covers as applicable
- Don’t wear highly conductive items on hands or arms

Control Measures
Laser Generated Air Contaminants (LGAC)

- Control measures
  - Exhaust ventilation
    - Hoods, ducts, air cleaners, and fans
    - Comply with latest version of *Industrial Ventilation & Fundamentals Governing the Design & Operation of Local Exhaust Systems* (ANSI Z9.2)
  - Respiratory protection
    - Used to control brief exposure or as interim control until engineering control are put in place
    - Compliance with OSHA (29CFR 1910.134)
Control Measures: Compressed Gas

- Hazardous gases shall be contained in an approved exhausted gas cabinet
- Shall have a sensor and alarm to detect leaks
- Shall be stored according to OSHA and Compressed Gas Association requirements

Time to summarize and ask questions

- Do you now understand the potential hazards and risks?
- Is laser safety achievable, the answer is YES!
- If you understand the hazards, you will take appropriate hazard control measures.
- Your laser safety program can be
  - Maintenance mode
  - Pro-active mode
  - You need to decide what fits you best and your resources
  - Does your program take effort? Yes!
Thank You!

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