Laser Safety:

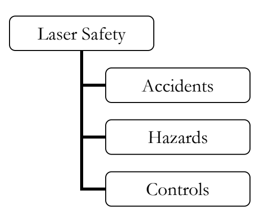
Hazards, Bioeffects, and Control Measures

Laser Institute of America

Gus Anibarro

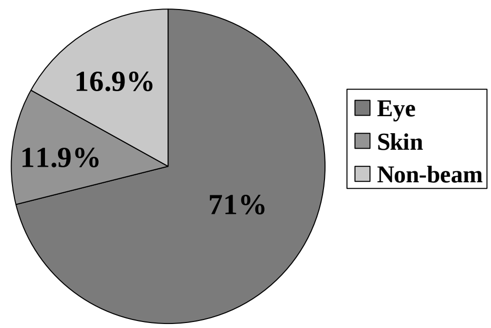
Education Manager

Laser Safety Overview



Laser Accidents & Incidents: Overview from one 1999 Survey

- Top 5 lasers: Nd:YAG, Ar, CO_2, 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

 3

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%

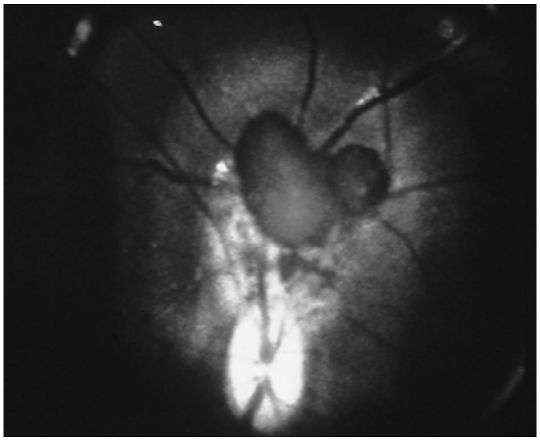
Data from Rockwell, RJ, ILSC 99 Proceedings, LIA

 4

Laser Accidents

Eye Injury

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



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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)**

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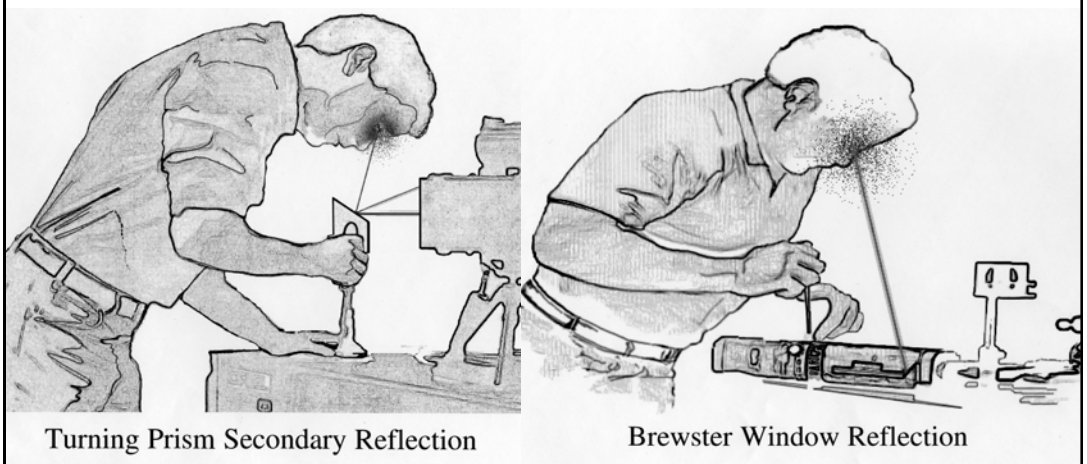
Many laboratory accidents result from unexpected upward reflections



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From Sliney, DH, *Optics and Photonics News, pp 31-37 (1997)*

7

Laser Accidents

- Cause of accidents
  - Not using eyewear (may have been available)
  - Incorrect eyewear selection and/or eyewear failure.
  - Improper fit

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8

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

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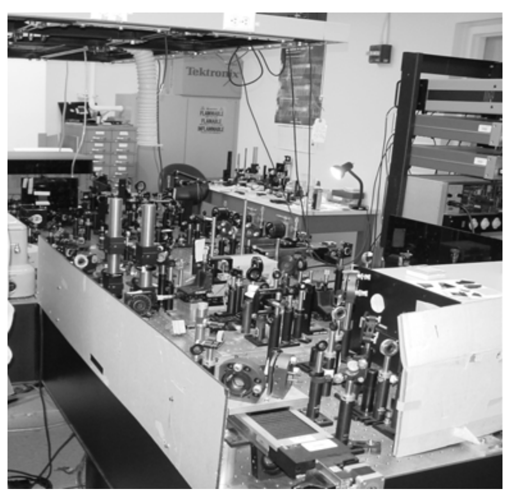
Laser Accidents:
Most Hazardous Acts – Beam Alignment

- 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



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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

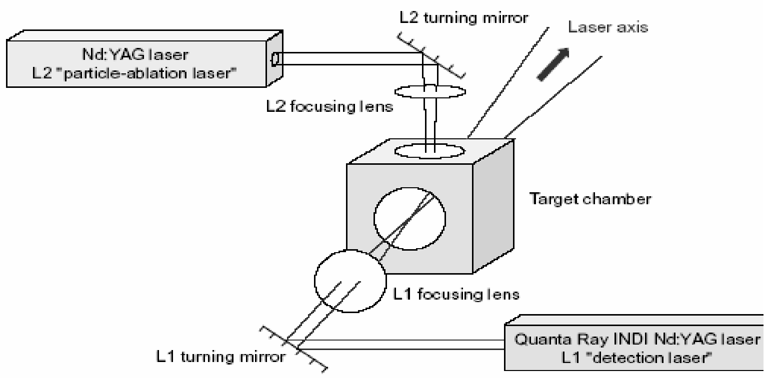

Figure 2.6. A diagram of the experimental system setup, showing the beam path along the L1 axis, through the target chamber, and out the chamber's rear window.

Laser Accidents:
Incident at DOE Laboratory

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

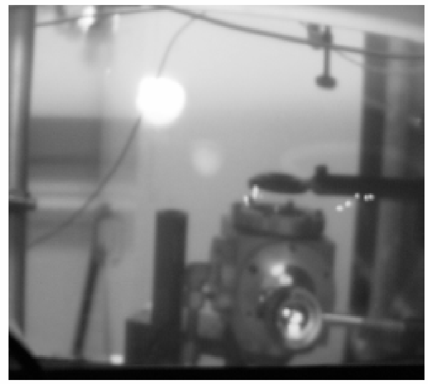

Figure 3.1. IR image of the transmitted laser pulse image on the back wall.

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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

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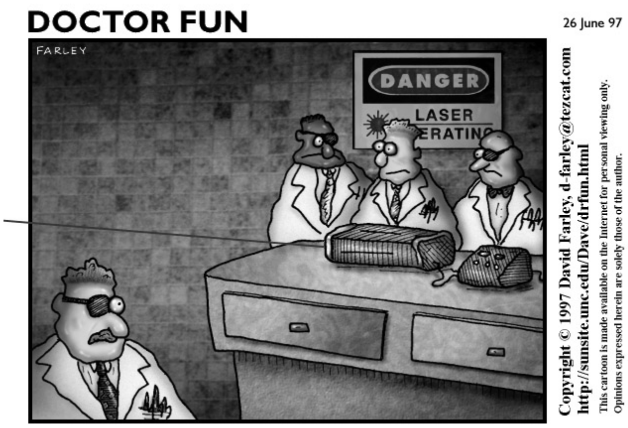
Learning from Laser Accidents

- In most cases, there is a heightened interest in laser safety after a colleague is injured….
- But not always…



Peer pressure in the laser lab

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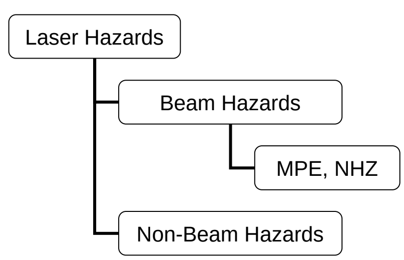
Laser Hazards Breakdown



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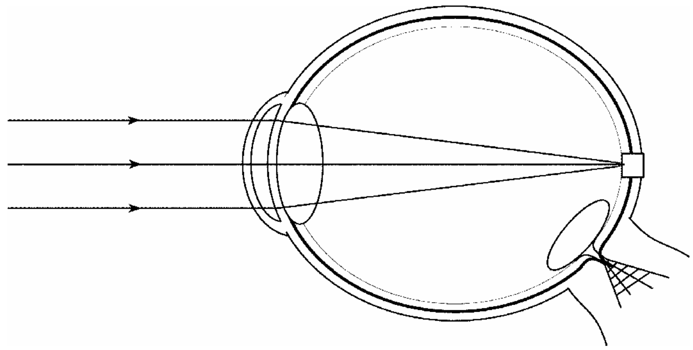
Beam Hazards: Optical Concentration by the Eye



- 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/cm^2, becomes 100 kW/cm^2 at retina!

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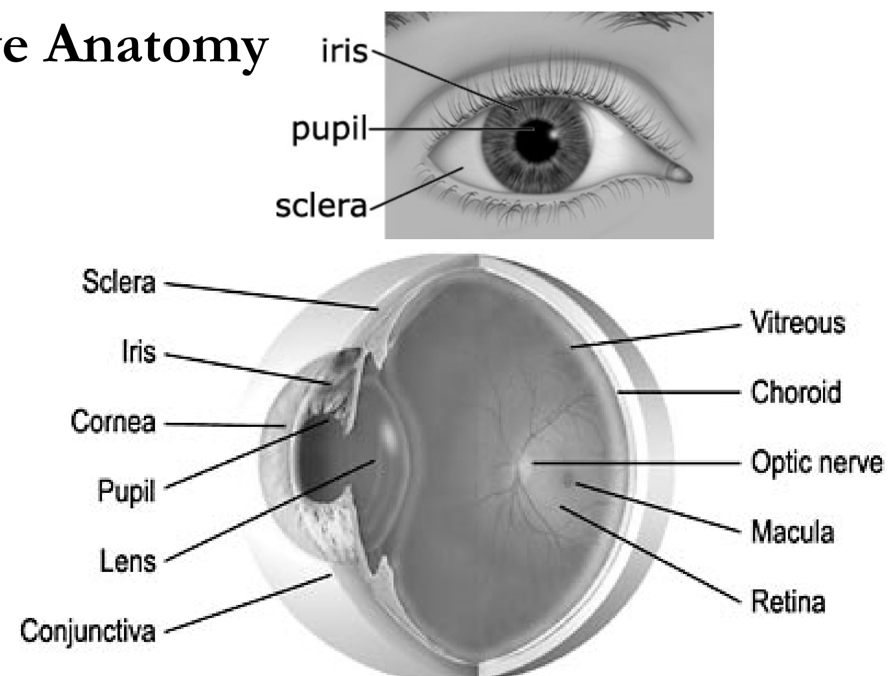
Eye Anatomy



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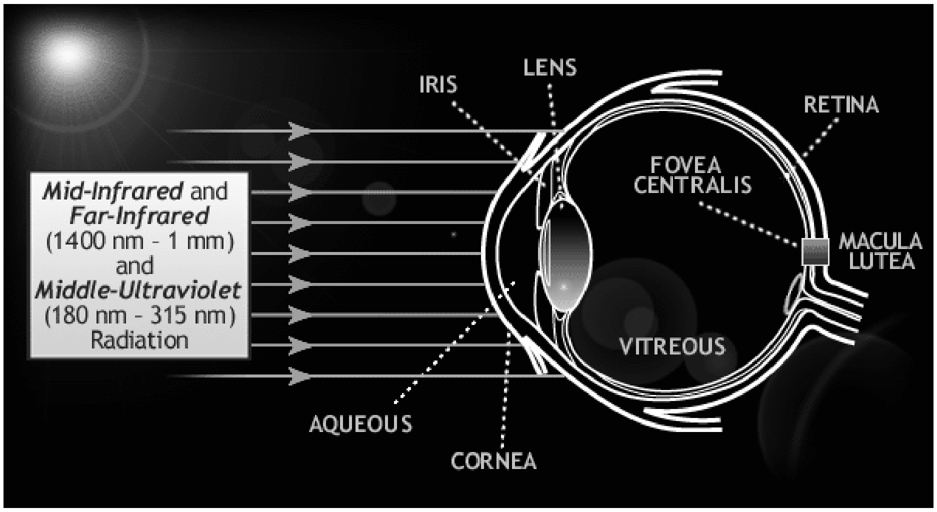
Ocular Absorption Site vs. Wavelength:
UV-B, UV-C, IR-B and IR-C



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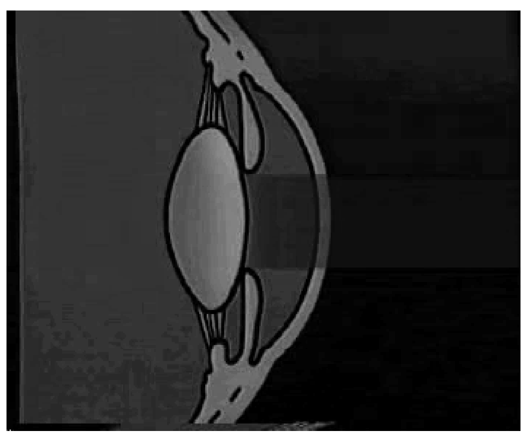
Beam Hazards

Corneal Thermal Burns

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



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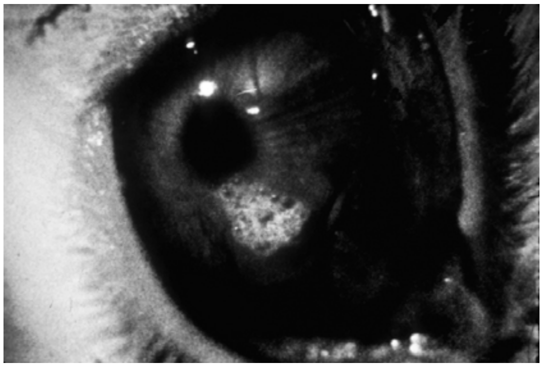
Beam Hazards

Corneal Thermal Burn



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

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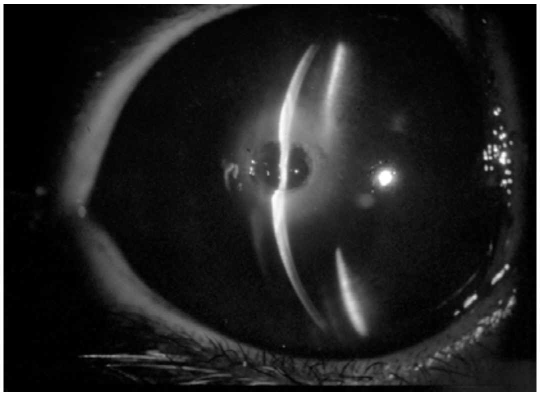
Beam Hazards

Corneal Thermal Burn



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

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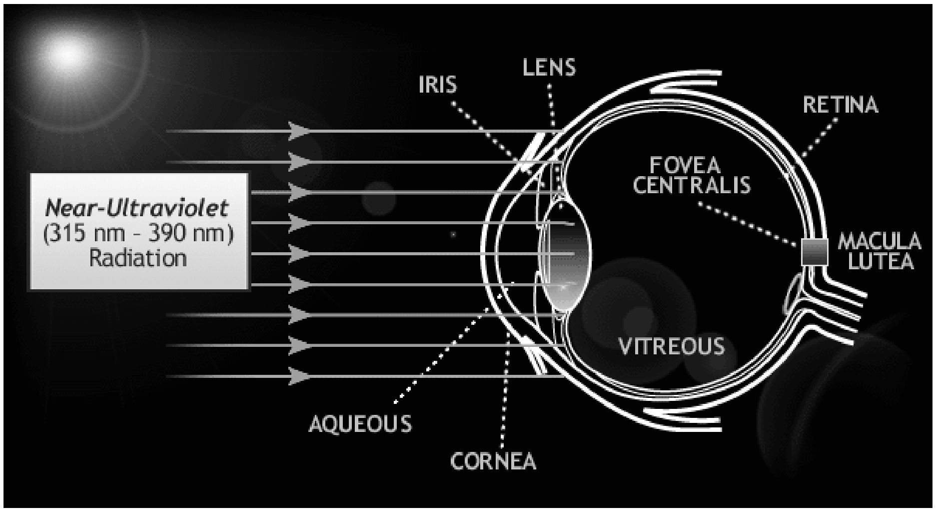
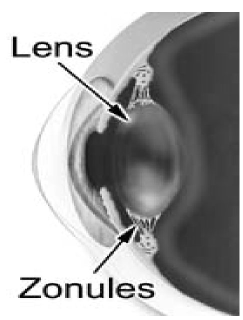
Ocular Absorption Site vs. Wavelength: UV-A



The Lens

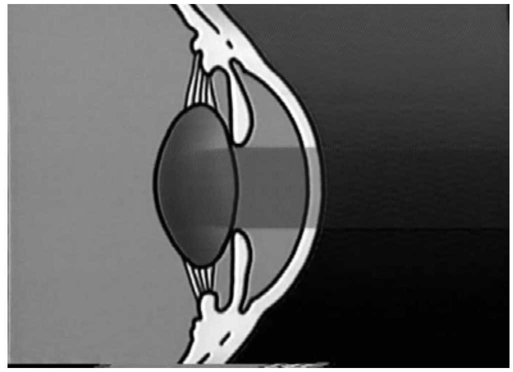
- Lens - Provides accommodation, the ability to focus on near objects;
- very slow metabolic rate and limited ability to repair injury;
- becomes less pliable with age, resulting in presbyopia;
- becomes cloudier with age and eventually opacifies, i.e., a cataract is formed.

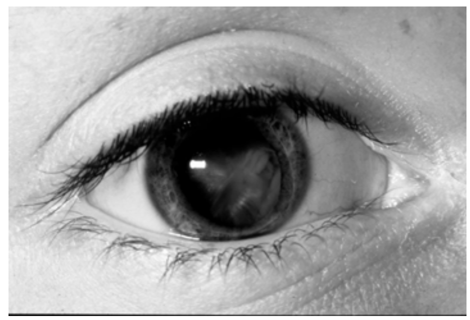


Cataract

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.





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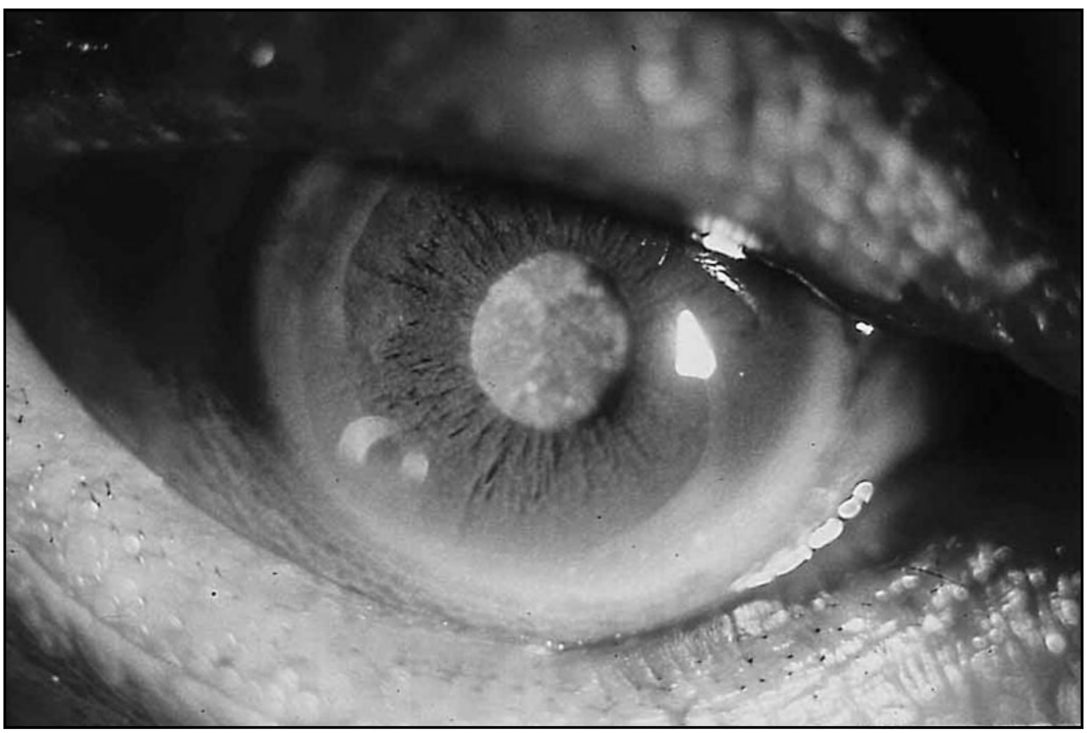
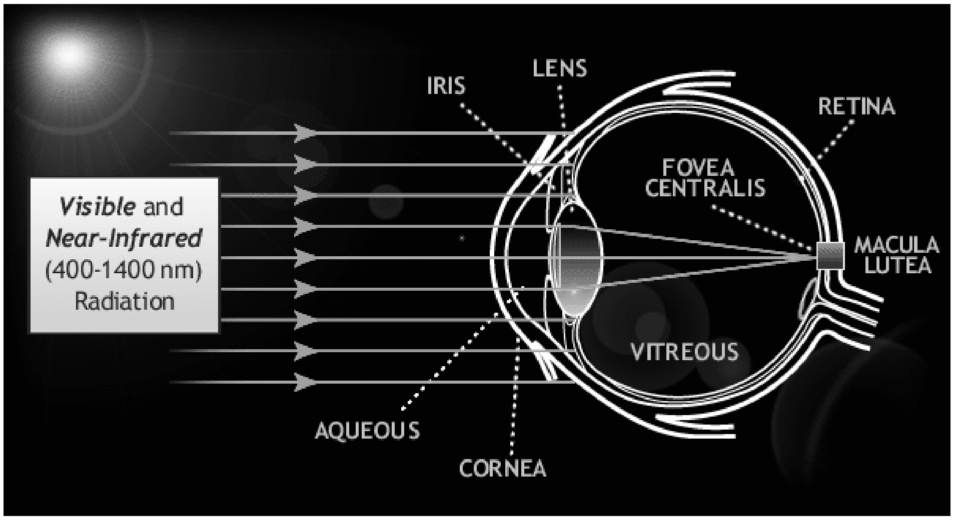


Ocular Absorption Site vs. Wavelength:

the retinal-hazard region, Visible and IR-A (400-1400 nm)



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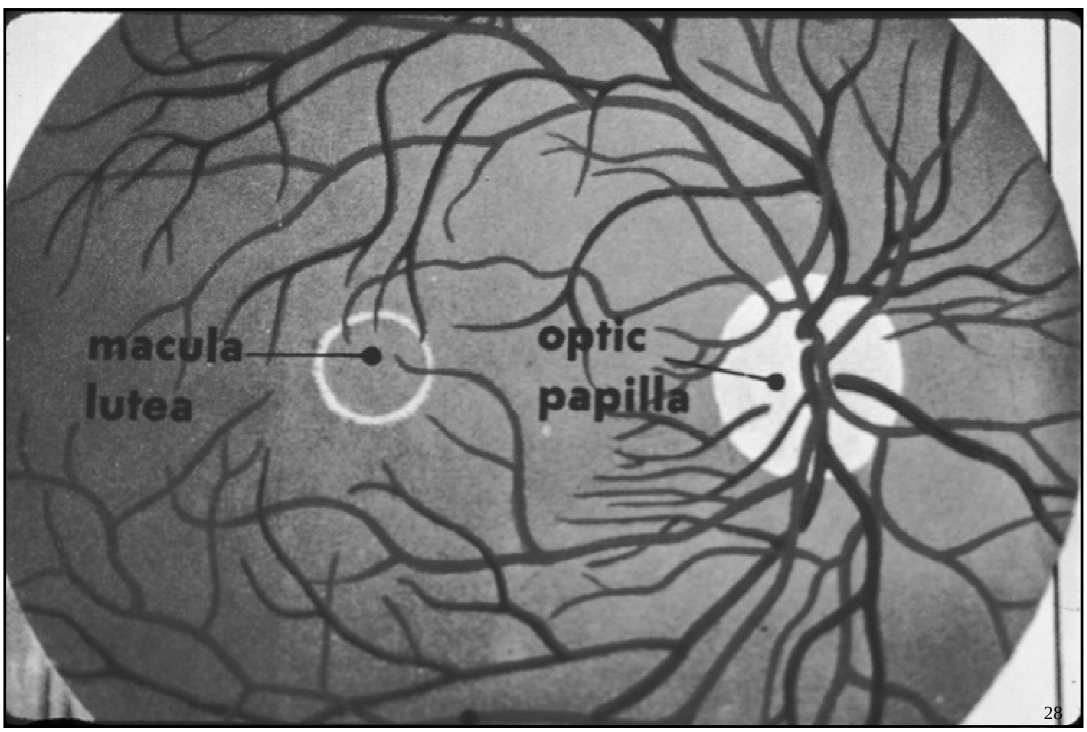
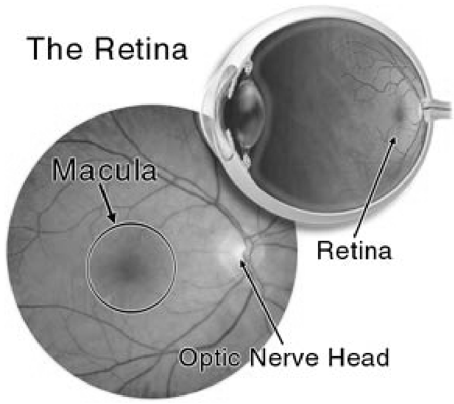


28

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.



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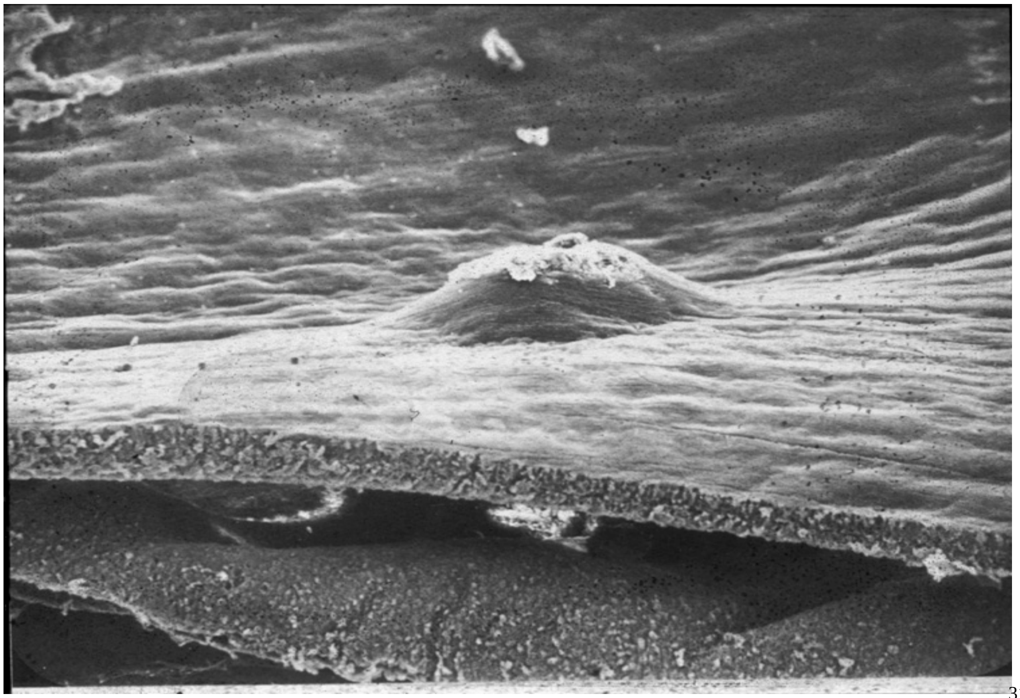

31

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)

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Beam Hazards
Maximum Permissible Exposure (MPE)

- 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).

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Maximum Permissible Exposure (MPE)
Summary of Five MPE Examples for CW Lasers

Laser Type	Eye or Skin MPE	MPE [W/cm^2]	Exposure Duration
CO_2	Eye	0.100	10 s or longer
Visible	Eye	0.00255	0.25 s
Nd:YAG	Eye	0.0050	10 s or longer
CO_2	Skin	0.100	10 s or longer
Nd:YAG	Skin	1.00	10 s or longer

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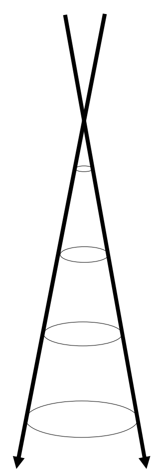
Beam Hazards
The Nominal Hazard Zone (NHZ)

- The NHZ is the space within which the level of direct, reflected or scattered laser light exceeds the MPE level for the laser.



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The Nominal Hazard Zone, NHZ:
Laser Criteria Used for NHZ Calculations

Laser Parameter	Nd:YAG	CO_2	Argon
Wavelength, λ, (μm)	1.064	10.6	0.514
Beam Power, Φ, (W)	100	500	5.0
Beam Divergence, ϕ, (mrad)	2.0	2.0	1.0
Beam Size at Aperture, a, (mm)	2.0	20.0	2.0
Beam Size at Lens, b, (mm)	6.3	30.0	3.0
Lens Focal Length, f_o, (mm)	25.4	200	200
MPE, 8 hr (Wcm^{-2})	5×10^{-3}	0.1	1×10^{-3}
MPE, 10s (Wcm^{-2})	5×10^{-3}	0.1	________
MPE, 0.25s (Wcm^{-2})	________	________	2.5×10^{-3}

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

Nominal hazard distance (m)

Laser Type	Exposure Duration	Direct	Lens-on Laser	Diffuse
Nd:YAG	10 s	790	6.4	0.8
CO_2	10 s	399	5.3	0.4
Argon	0.25 s	505	33.6	0.25

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)

 41

Non-Beam Hazards: Electrical

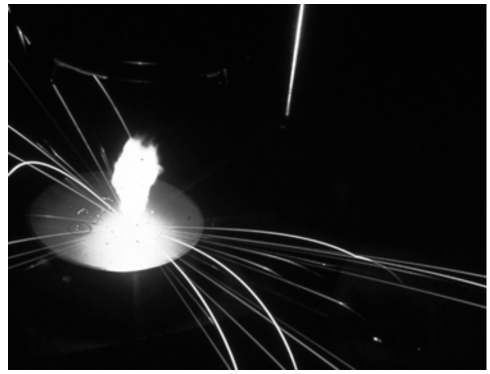
- Shock
- Electrocution
- Electrically generated fires
- ***Not*** unique to lasers
- Electrocution: 5th leading cause of work related injury/death in U.S.
- Electrocution: cause of at least 10 laser-related death
- 2nd most often reported cause of laser accidents

 42

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 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

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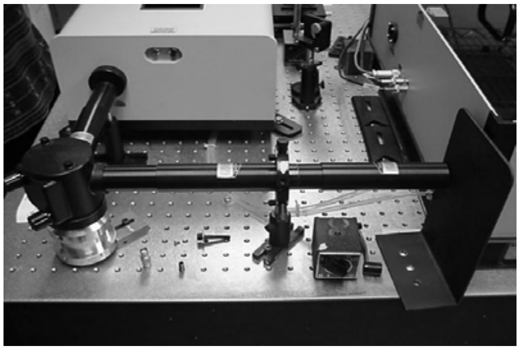
Control Measures: Enclosed Beam Path

- Tubular, anodized aluminum beam tubes provide rigid mounting
- Here, encloses beam from laser into beam bender then to regenerative amplifier.



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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

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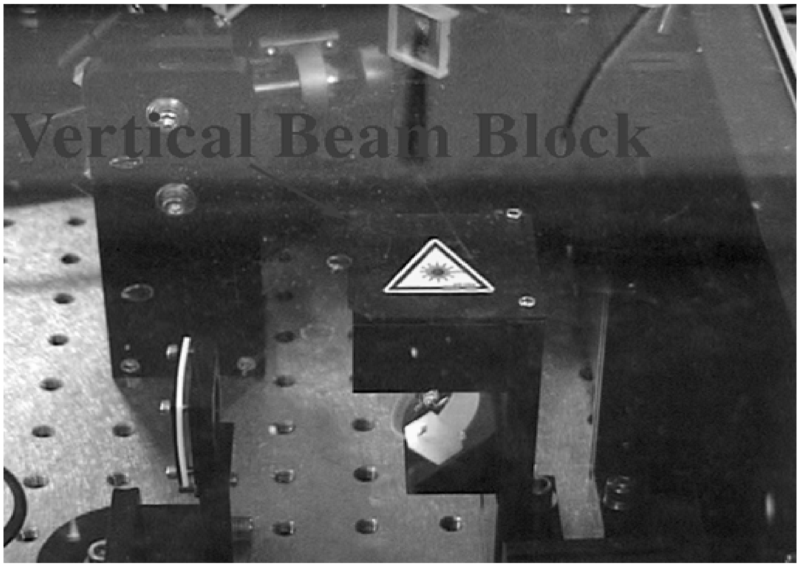
Control Measures: Beam Block



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Control Measures: Beam Stop

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

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Control Measures
EYE PROTECTION

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

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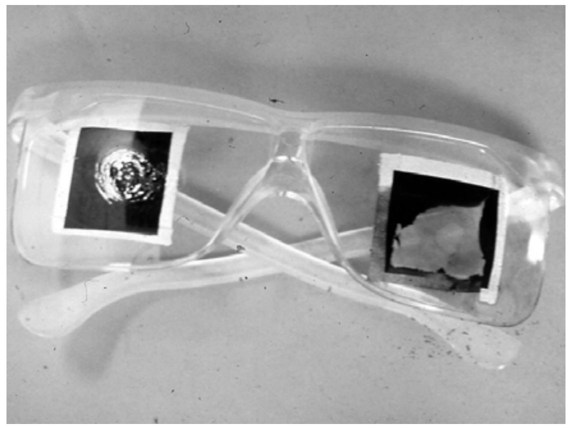
Control Measures
Wavelength Compatibility

- 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



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Control Measures
Optical Density

Eyewear must be marked with OD as a function of wavelength

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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

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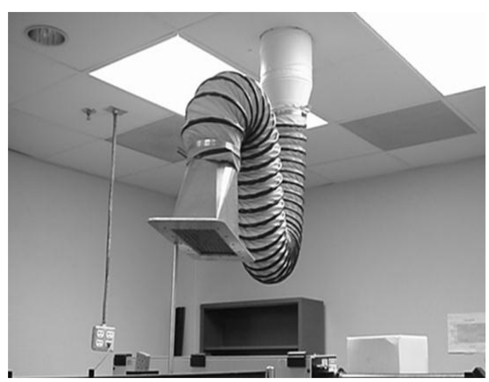
Control Measures
Laser Generated Air Contaminants (LGAC)

- 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)



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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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