MIT EHS
ENVIRONMENT · HEALTH · SAFETY

Laser Safety

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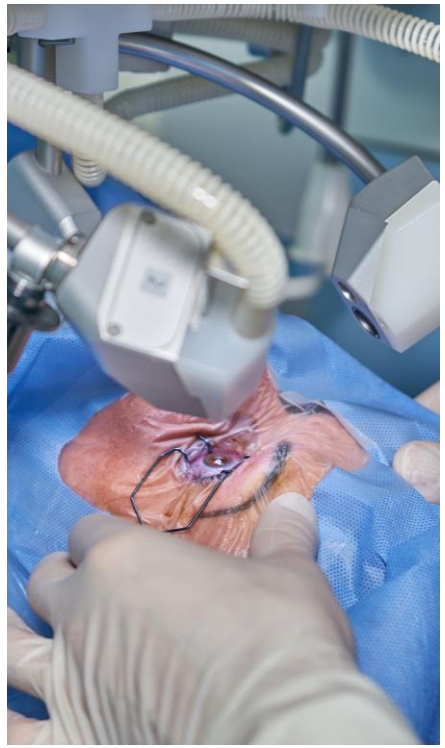
Laser Applications

Medical



Industrial

Research

Communication

Military

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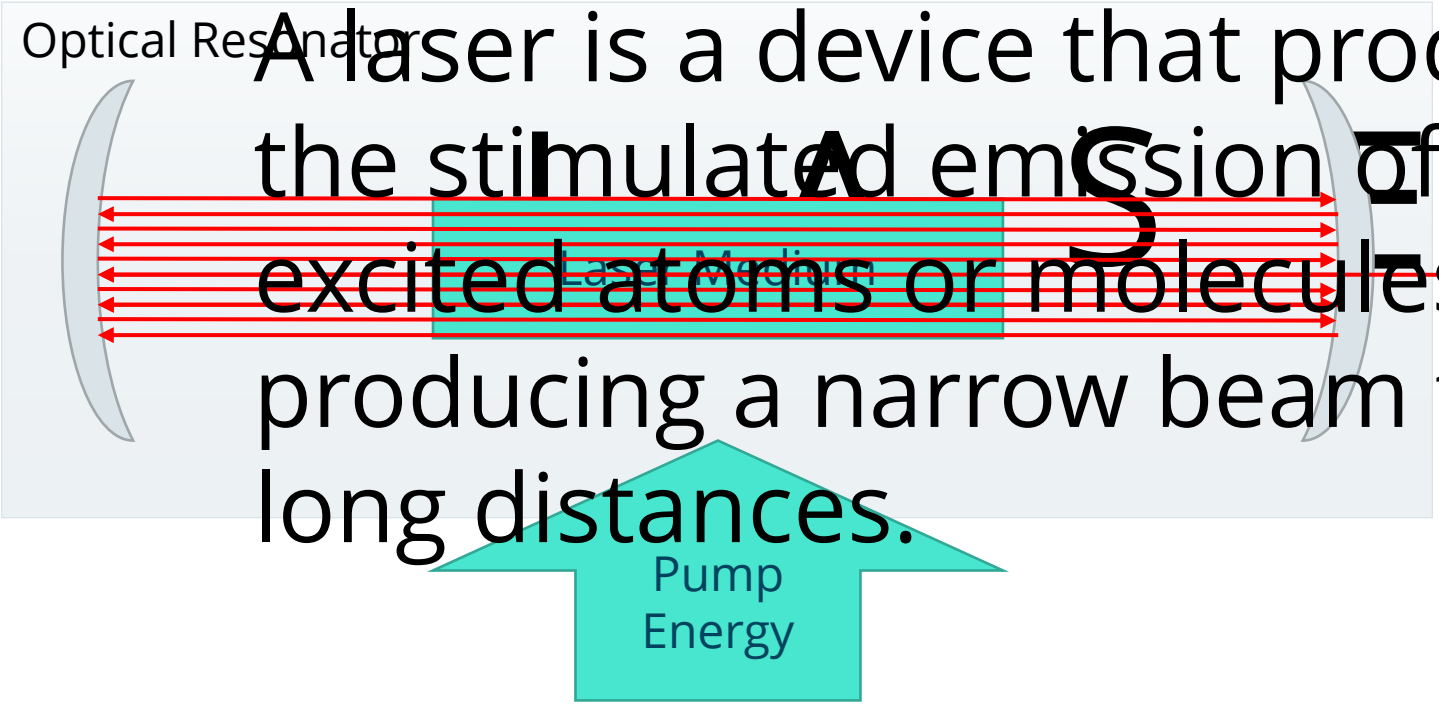


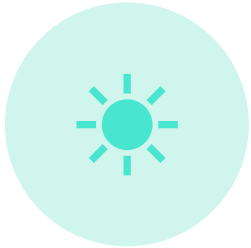
A laser is a device that produces light by the stimulated emission of photons from excited atoms or molecules, typically producing a narrow beam that can travel long distances.

Unique Properties of Laser Light

Monochromatic

Directional

Coherent



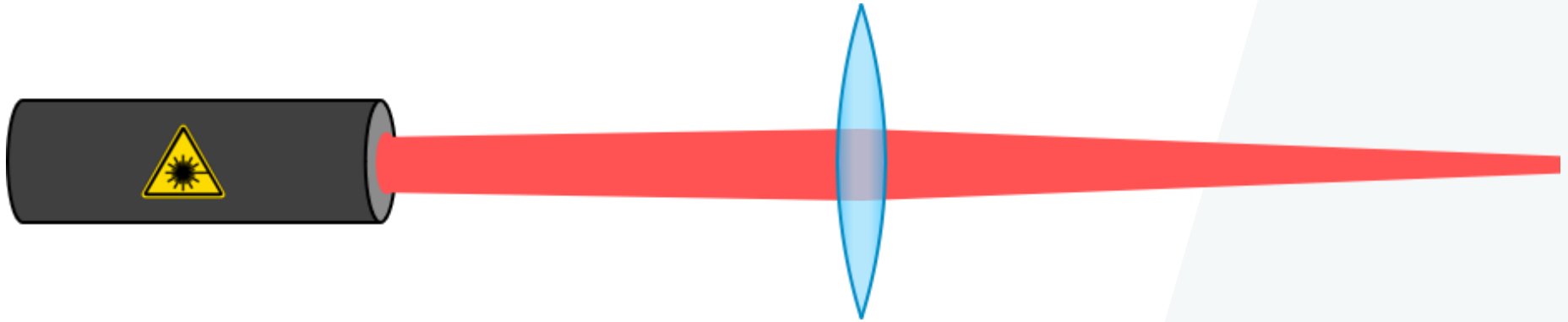
Intense

Irradiance and Radiant Exposure

- Damage depends on power or energy and spot size
- Irradiance (W/cm^2) and radiant exposure (J/cm^2) are used to determine damage thresholds
  - Maximum Permissible Exposure (MPE) is related to the damage threshold of the eye or skin
  - Materials, including barriers and eyewear

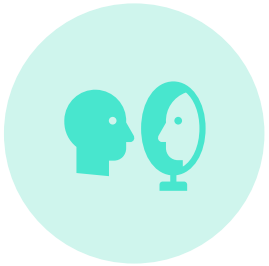
Changes in Beam Size

- Some optics change the size of the beam
- Irradiance/radiant exposure depends on beam size
  - Focusing the beam increases the hazard
  - Expanding the beam decreases the hazard.



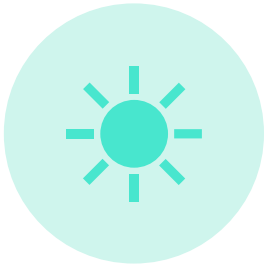
Beam Interactions

Transmission



Reflection

Absorption

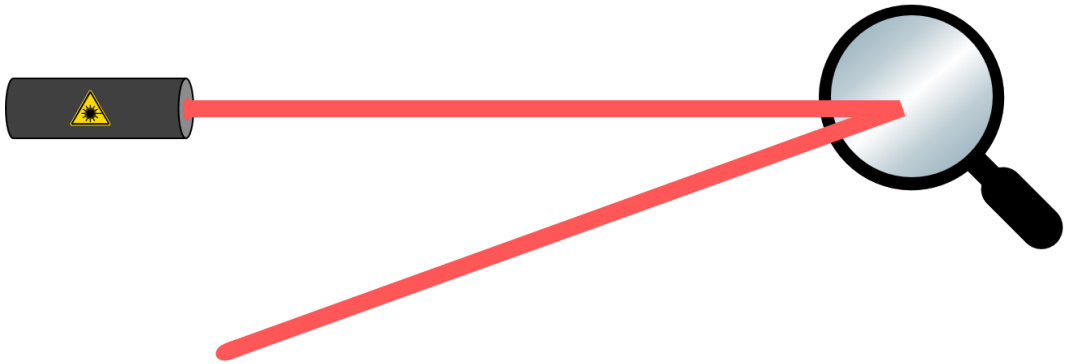


Scattering

Types of Reflections

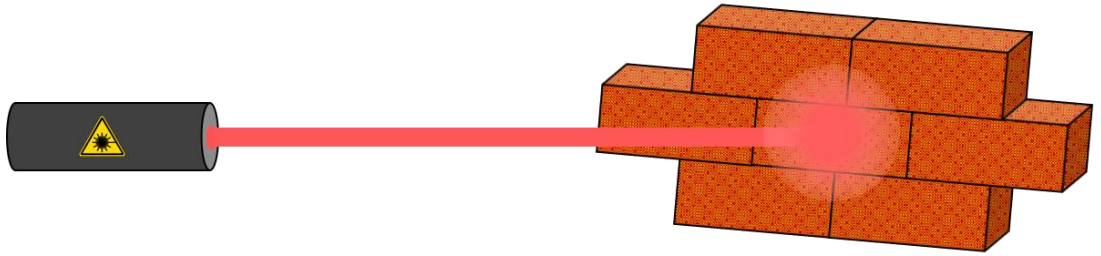
Specular Reflections

The beam reflects in one direction with little loss of energy; Remains hazardous for long distances



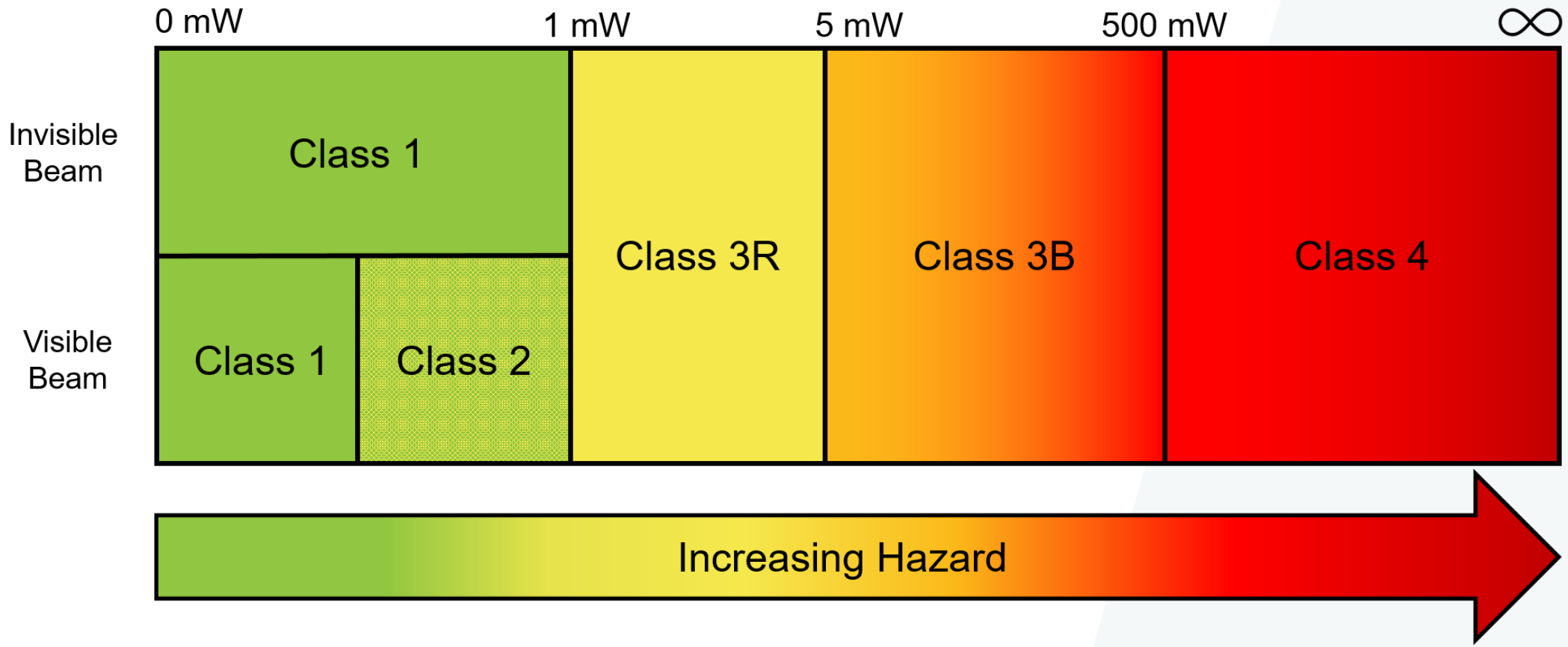
Diffuse Reflections

The beam strikes a rough surface and scatters in all directions; Can be hazardous for a short distance



Laser beams interact with any object in their path, not just optics. Tools, mounts, jewelry (especially lanyards and wedding rings), and cardboard can all transmit, reflect, scatter, or absorb the beam.

Laser Classification



Laser Cutters

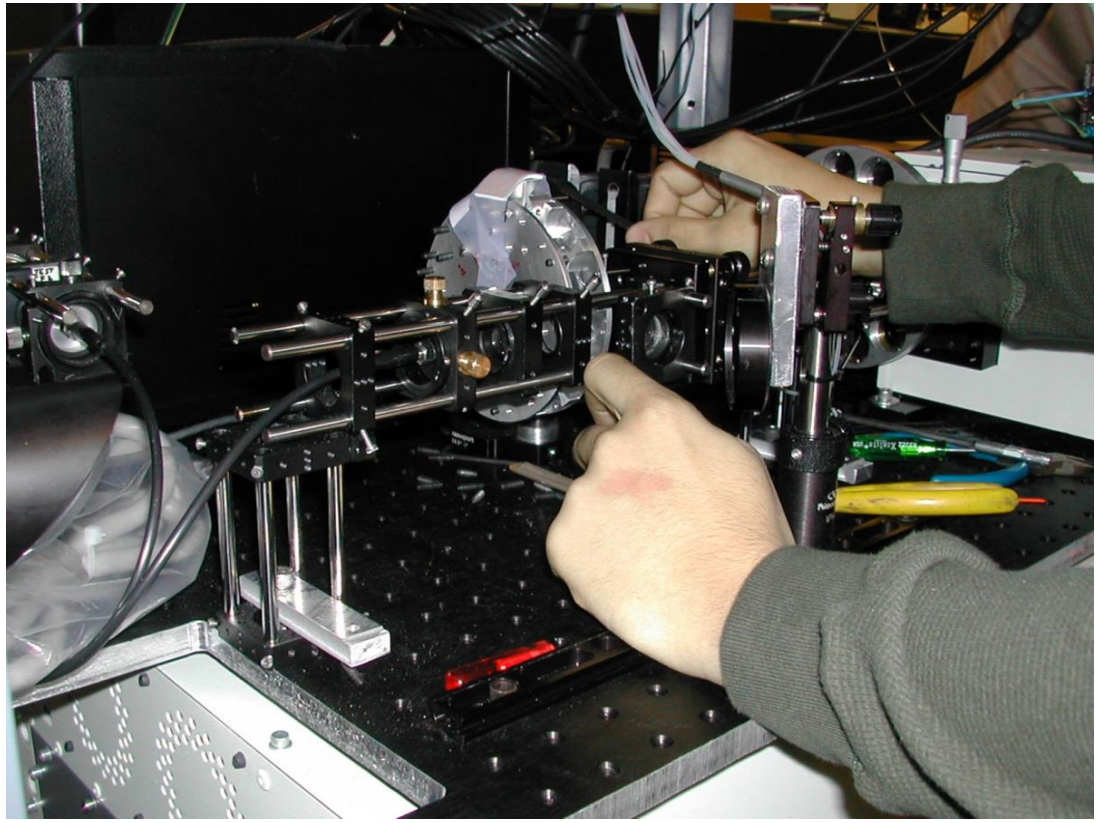
- Typically sold as Class 1 systems, although they usually include a Class 4 (often CO2) laser
- Its not correct to say they are “incapable of causing harm under ordinary operations”
- Laser cutter fires are extremely common
- Should not be run unattended
- Need proper ventilation

Biological Effects

The severity of the biological effect and the symptoms of a laser injury can vary significantly depending on the characteristics of the beam.

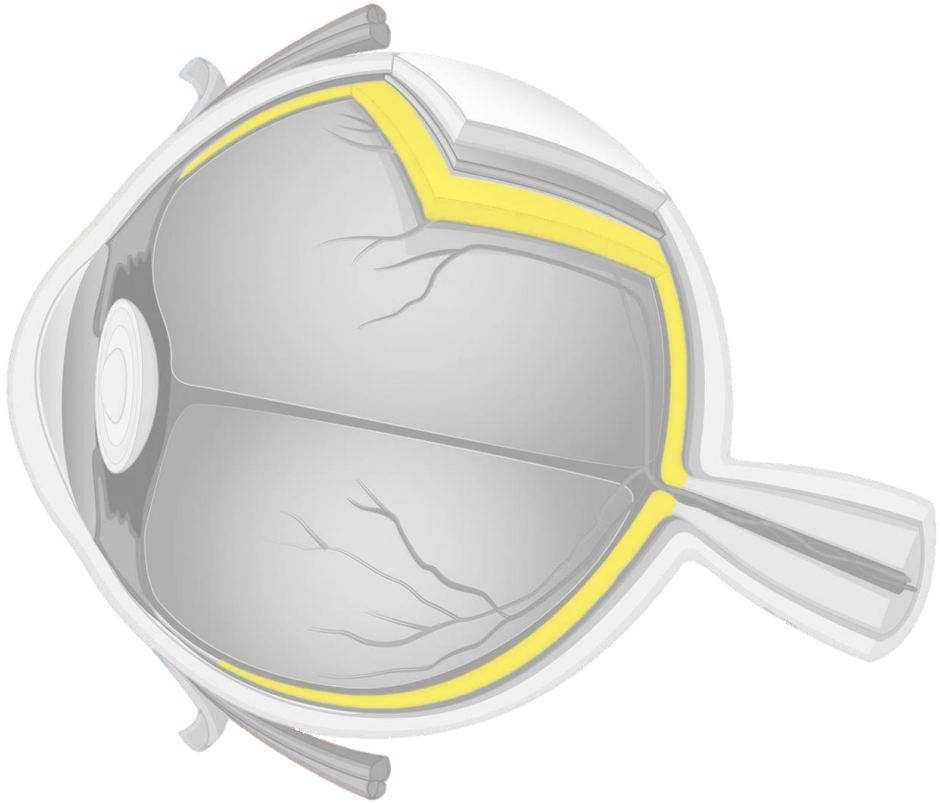
Skin Effects

- Thermal
  - All wavelengths
  - Depth of the burn depends on wavelength
- Photochemical
  - Ultraviolet wavelengths
  - Sunburn and skin cancer
- Shockwaves
  - Short laser pulses

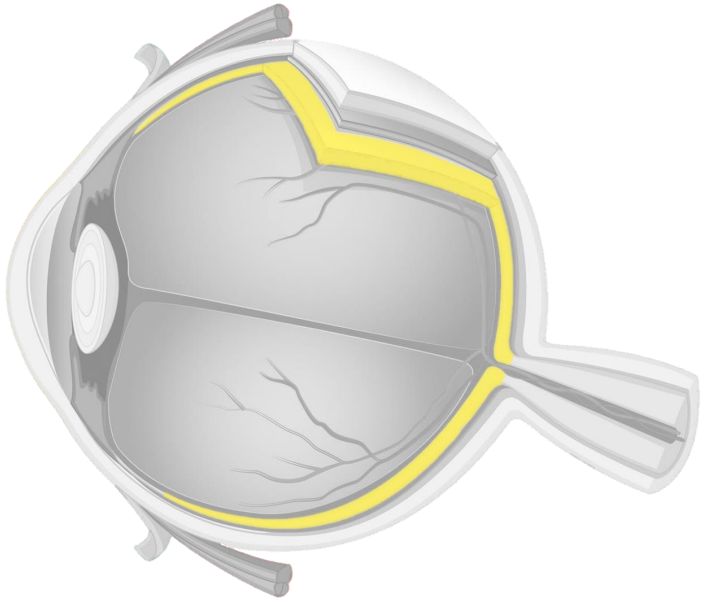


Anatomy of the Eye

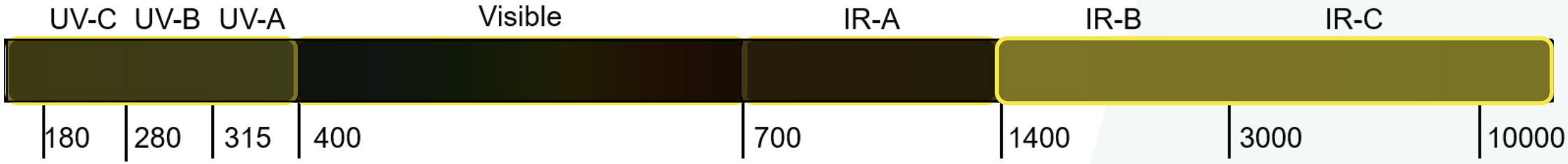
- The eye is an optical instrument designed to focus light onto the retina
- The retina acts like an array of sensors allowing the brain to interpret the collected light as an image
- There are three main structures in the eye which can be damaged by laser light



Wavelength Dependance



- Visible (400 – 700 nm)
  - Damages retina (all the eye)
  - Invisible to the eye
  - Retina safe, but not eye safe!
  - Immediate symptoms include:
    - Bleaching
    - Blindness
- UV-A (315 – 400 nm)
  - Damages cornea and lens
  - Invisible to the eye
  - Delayed symptoms may appear in 48h
  - Partial or total blindness
- UV-B (280 – 315 nm)
  - Damages cornea and lens
  - Invisible to the eye
  - Delayed symptoms may appear in 48h
  - Partial or total blindness
- UV-C (180 – 280 nm)
  - Damages cornea and lens
  - Invisible to the eye
  - Delayed symptoms may appear in 48h
  - Partial or total blindness
- IR-A (700 – 1400 nm)
  - Damages retina (all the eye)
  - Invisible to the eye
  - Retina safe, but not eye safe!
  - Immediate symptoms include:
    - Bleaching
    - Blindness
- IR-B (1400 – 3000 nm)
  - Damages cornea and lens
  - Invisible to the eye
  - Delayed symptoms may appear in 48h
  - Partial or total blindness
- IR-C (3000 – 10000 nm)
  - Damages cornea and lens
  - Invisible to the eye
  - Delayed symptoms may appear in 48h
  - Partial or total blindness



Nonbeam Hazards

Often times laser users become so focused on the “beam” hazards of their laser that they neglect the unexpected hazards from non-laser equipment.

Non-Beam Hazards

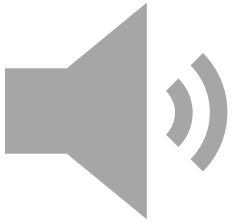
Electrical

Fire and Explosion

Chemical

Cryogens

Pressure



Noise

Non-laser radiation

Housekeeping

Common Non-Beam Hazards

Fire

- Irradiance greater than 10 W/cm^2
- Cooling failures, electrical shorts, heat from lamps
- Equipment can get hot and cause burns

Electrical

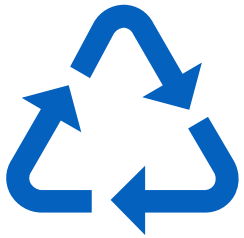
- High voltage power supplies
- Ground optical table and other equipment
- Cable routing
- Raise electrical equipment off floor

Chemical

- Laser media (e.g. dye and excimer)
- Solvents
- Laser-Generated Air Contaminants (LGAC) when irradiance exceeds 10^3 W/cm^2

Laser-Generated Air Contaminants

Decomposition products of various target materials, especially plastics, metals and tissues, can result in air contaminants at high irradiances (~10^3 W/cm^2)



Plastic

Tissue

Metal

FORBIDDEN
LASER MATERIALS

MATERIAL	DANGER	
PVC (Polyvinyl Chloride)	Emits pure chlorine gas	Corrosive gas will ruin lens, corrode metal, and ruin motion control system.
Pleather / Artificial Leather	Emits pure chlorine gas	Corrosive gas will ruin lens, corrode metal, and ruin motion control system
Moleskin Notebooks	Emits pure chlorine gas	Corrosive gas will ruin lens, corrode metal, and ruin motion control system
Polycarbonate / Lexan	Cuts poorly, discolors, fire	Black and yellow gas is toxic. This material also absorbs infrared radiation, so the laser is ineffective
ABS	Emits cyanide gas and melts into the machine	ABS melts, making a mess, leaving a jagged edge and is prone to catching fire
HDPE / Milk Bottle Plastic	Catches fire and melts	HDPE tends to melt and fuse to the material bed
Polystyrene Foam	Catches fire	Tends to catch fire and melt. **This is the #1 material that causes laser fires**
Polypropelyne Foam		Like Polystyrene, poly pro foam melts and catches fire. The drips continue to burn and make a mess.
Fiberglass	Emits fumes	This is a combination of 2 materials that don't cut: glass only etches, and epoxy resin fumes.
Coated Carbon Fiber	Emits Noxious Fumes	A mix of 2 materials. Carbon fiber mat can be cut with some fraying, but not when coated.
Any Powder	Inhalation hazard	Powders will be blown away by the air forced through the nose cone.
Printed Circuit Boards (Fr4, G10)	Emits fumes	

MIT | Pappalardo Lab

Laser Cutter Concerns

- Laser-Generated Air Contaminants (Especially for PVC, pleather, polycarbonate, ABS, fiberglass, PCBs)
- Fire (any material, but especially HDPE and polystyrene and polypropylene foam)
- Interlocks and Ventilation

Laser Cutter Fires

https://www.bbc.com/news/uk-england-hampshire-34814476

Laser Cutter Fires

https://www.boisestate.edu/coen-mbe/2021/03/11/cool-heads-contain-eis-fire/

Laser Cutter Fires

Laser Cutters are Class 1 laser products – but still dangerous

Control Measures

The hazards of laser systems can be minimized by careful planning and experimental design.

CC: https://www.flickr.com/photos/fagorautomation/12434755954/in/photostream/

Types of Controls

Engineering Controls

Facility Design

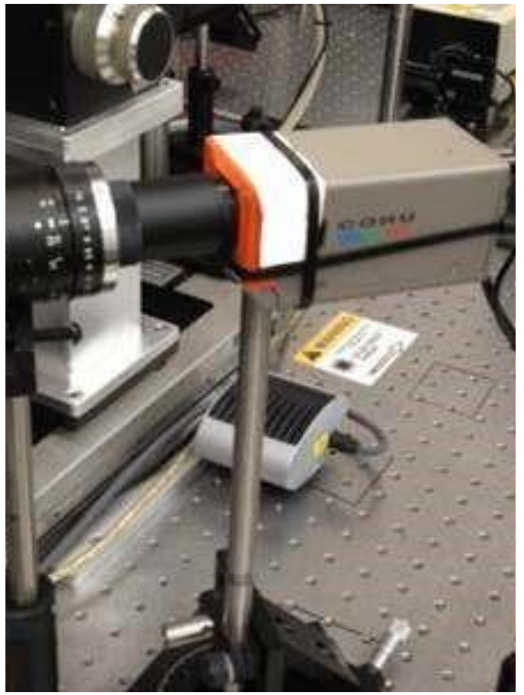
- Entryway/Interlocks
- Window covers
- Access control
- Ventilation

Enclosures

- Opaque/transparent
- Table curbs
- Laser curtains
- Beam tubes

Beam Stops

- Beam blocks
- Beam dumps
- Safety shutters



Remote Viewing

- Cameras
- Control rooms

Administrative Controls

Training

- General training
- Lab-specific training

Registration

- Principal investigators
- Laser users
- Laser systems

Inventory

- List of lasers and their operating parameters
- Central inventory maintained by RPP

Laser Safety Procedure

- Documents how the laser system is to be used
- Approved by RPP
- Posted near the laser

Hazard Analysis

- Performed by RPP
- Initial assessment
- Following major changes

Postings and Lights

- Signs describe hazard and required PPE
- Flashing lights indicate hazardous conditions

Laser Safety Procedure

Description

- Laser type(s)
- Wavelengths
- Application
- Average power or energy per pulse
- Pulse duration and frequency

Hazards

- Eye and skin hazards
- Electrical hazards
- Possible air contaminants

Controls

- Proper eyewear location with OD and wavelength
- Define controlled area and entry protocol
- Reference equipment manual

Personnel

- List of authorized laser users
- Record of laser-specific training

Procedures

- Start-up and shutdown
- Ordinary operation
- Alignment
- Emergencies

Control Measures in the Lab

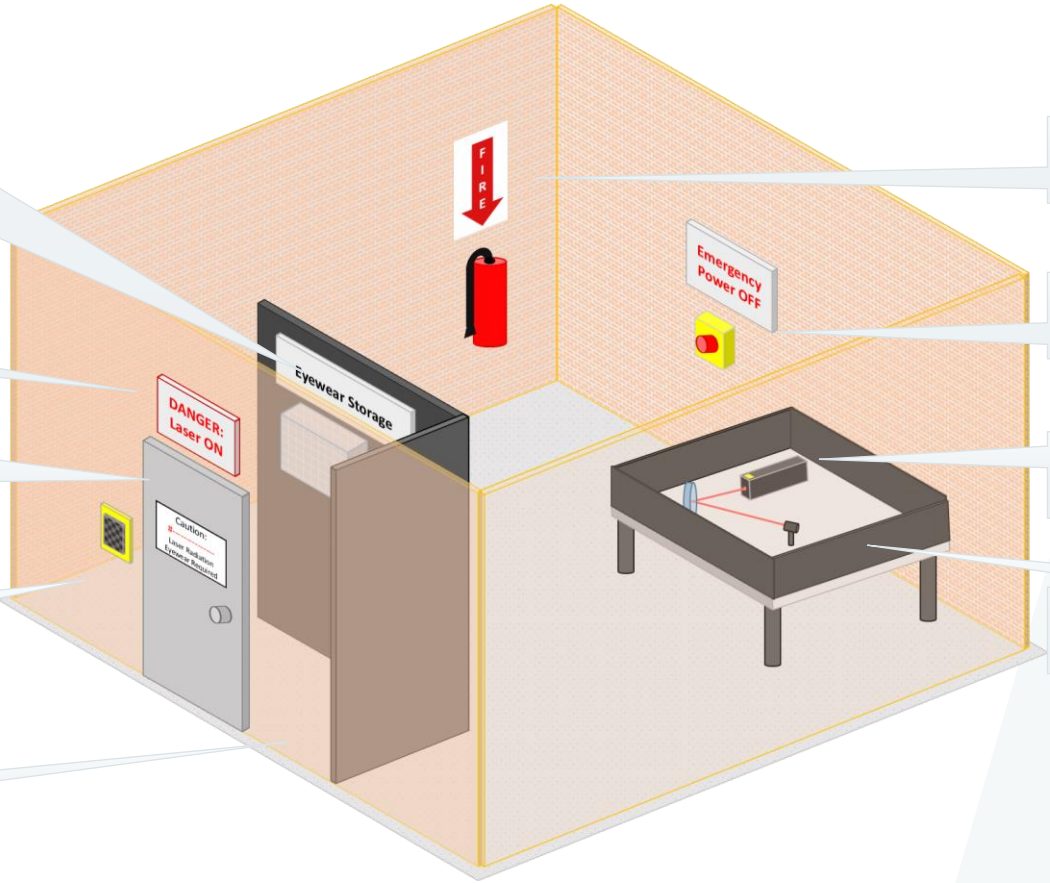
Eyewear Storage

Laser Light

Warning Sign

Access Control

Entryway Barrier

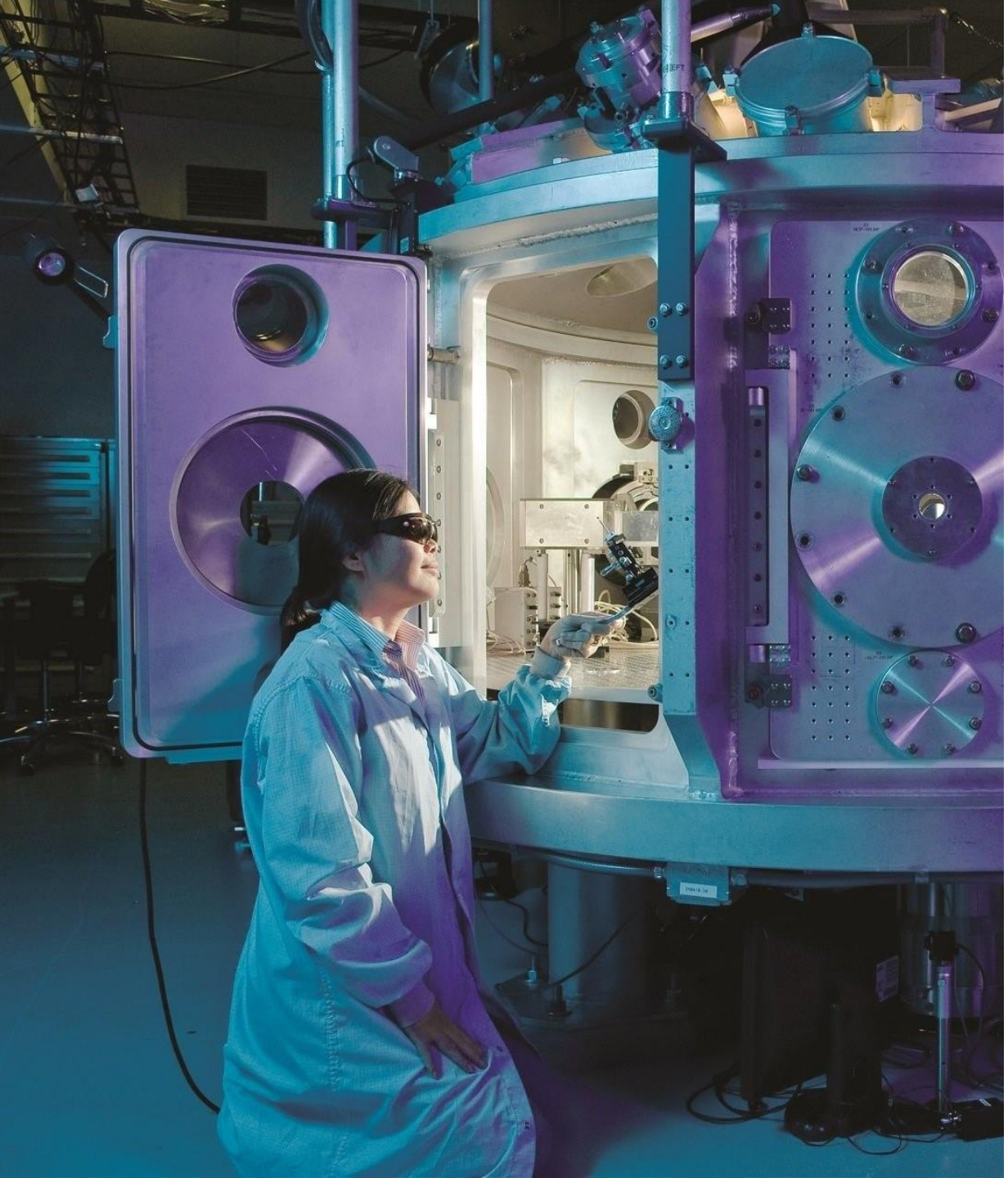


Fire Extinguisher

Emergency Power Off

Labels

Enclosures



Personal Protective Equipment

- Laser eye protection
- Lab coat
- Gloves
- Other depending on hazards

Laser Eye Protection

Optical Density (OD)

Visible Light Transmission (VLT)

Field of View

Fit and Comfort

Damage Threshold

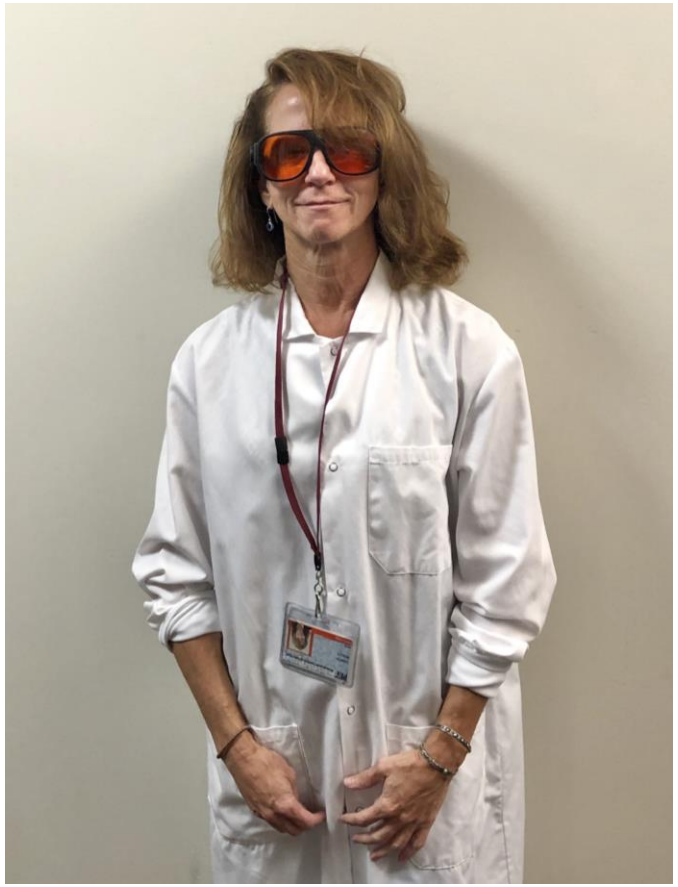
Pulse Length

Optical Density (OD)

- Order of magnitude reduction in transmission
- Printed on the eyewear
- Required OD determined by hazard analysis

OD	Reduces by
1	10
3	1,000
7	10,000,000

Attire for Laser Work



- ☑ Appropriate PPE ☑
- ☒ Jewelry removed ☑
- ☒ Long sleeves ☑
- ☒ Hair pulled back ☑
- ☒ Lanyards secured ☑

Best Practices

Exclude unnecessary personnel

Reduce beam power

Block beam when adjusting optics

Use sensor cards, cameras, and other viewers

Verify correct eyewear

Secure optics to table

Use enclosure and beam blocks

Check for stray beams

Case Study: The Death Star

Star Wars was extremely confused about lasers, but let's assess their safety practices

The Death Star Superlaser

Death Star Laser Hazard Analysis

- Enclosure ☑
- Control Room ☑
- Laser Safety Procedure ☑
- Access Control ☒
- Eyewear ☑

Questions?

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