Laser Safety
Laser safety can be defined as optimizing the safe design and use of laser equipment to further the use of laser technology with minimum risk to safety and health.

Identifies surgical smoke from both laser and electrosurgical procedures as a health hazard. Cites smoke as an equal hazard to that of Bloodborne Pathogens and refers to OSHA 29CFR., NIOSH Hazard Controls: Control of Smoke From Laser/Electric Surgical Procedures


Contents of particulate
- Inorganic chemicals
- Chemicals such as CO, CO₂, Sulfur and Nitrogen Compounds
- Permissible Atmospheric Levels of inorganic gases as published by OSHA/NIOSH are routinely exceeded during Laser and ESU Procedures
- Hypoxia and other symptoms normally associated with breathing these contaminants

Contents of particulate
- Organic Chemicals
- Burning breaks down the tissue into pyrolized by-products: Benzene, Toluene, Hydrogen Cyanide, Formaldehyde, polynuclear aromatic hydrocarbons, etc.
- Organic chemicals have been associated with headache, fatigue, weakness, and respiratory problems.
Contents of particulate

- **Microorganisms**
- Laboratory testing has shown that Bacteria, Fungi and Viruses are present in pyrolyzed smoke.
- Whether Open or Endoscopic procedure: Smoke is a problem for both Healthcare Worker and Patient
- Odors & smells cause nausea, headache and other symptoms in healthcare workers

Dr. Tennant developed **idiopathic thrombocytopenic purpura (ITP)** he believes was caused by airborne corneal particles or viruses contained in the plume generated from the laser. Dr. Taravella states laser plume should be treated as potentially biologically hazardous material and should be evacuated and filtered removing potentially infectious virus.

*Ophthalmology News,* “OSHA prepares guidelines to deal with laser surgery, which may be more dangerous to the surgeon than previously thought.”

Gregory Sandler Contributing Editor with Gerald L. Tennant, MD, Michael J. Taravella, MD, Michael S. Korenfeld, MD, Michael Fluharty/OSHA, Debbie Hornback/NIOSH -.

**Excimer laser surgeons developing a chronic cough or other illness.**


**Excimer laser plume particles generated during excimer laser corneal ablation.**


Raman spectrophotometry: laser light-scattering technique, most of plume is water

110 nm at 720 µm

149 nm at 150 µm

**Dynamics of ablation**

**Respirable particles in the excimer laser plume**


0.22 µm ± 0.056

SEM

≥ 5 µm on the walls of the nose, nasopharynx, trachea, and bronchial bifurcations.

≥ 2 µm respiratory bronchioles and alveoli

Particles less than 0.5 µm in diameter tend to be exhaled
• Long-term inhalation of CO$_2$ laser smoke on the lungs of rats
• Fine particulate matter produced by tissue vaporization was deposited in the alveoli of the study animals and produced pathologic changes consistent with *interstitial pneumonia*, *bronchiolitis*, and *emphysema*. The severity of these changes increased proportionately as a function of the duration of exposure; the changes were similar to pulmonary changes in humans caused by inhalation of fine particles of asbestos, tobacco, talc, and other material.


Most particles are just the right size to be captured in the lung!

**Plume** elements collected from:

- VISX filter ~ 0.3 micron pore size [parallel air flow]
- MASTEL “Clean Room” ~0.2 micron pore size [uses orthogonal air flow]
- *Mastel Precision Instruments, Rapid City, So. Dak.*
- Filter stored at –70 Degrees Celsius until analyzed

VISX and MASTEL filters were analyzed with:

- **Scanning Electron Microscopy**, with and without fixation with 1% glutaraldehyde
- **Chemical Characterization** with:
  - *Scanning Electron Microscopy* and *Chemical Characterization* with:
    - With *Spectrophotometry* and *MALDI – TOF Mass Spectrometry*
    - Hydrophilic extracts with methanol
    - Hydrophobic extracts with chloroform

The MASTEL and VISX filters used
**Chemical Characterization**

Preliminary analysis with Mass Spectrometry

- The methanol extracts reveal multiple proteinaceous fragments – probably degraded proteins and/or nucleic acids.
- The proteinaceous fragments have Molecular Weights greater than 100 MW. Proteins of this magnitude or greater are known pathogens to the human body.

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*Polyacrylamide gel electrophoresis of nonhydrolyzed particles reveals large amino acid content.*

- These macromolecular fragments are likely small peptides, from degraded protein and lipid fragments from the cell membranes.
- Some of these peptides are greater than 1000 MW.

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Spectrophotometric Analysis of Methanol Extracts of Filters from LASIK Smoke Evacuators

Note relative absorption peaks in 250-300 nm range; indicative of aromatic organic molecules (e.g. amino acids, nucleic acids, etc.)
Low Ports Evacuation
High Port Evacuation
Fiber Optic

Summary
This study proves the presence of large proteinaceous molecules in the excimer plume in live patients.

These macromolecules are the size of known particles that cause emphysema, asthma, pulmonary fibrosis, and COPD.

Summary
The Local Evacuation System clinically and macroscopically removes and eliminates the majority of the plume, as evidenced by the SEM photos.

Tired of Huffing Excimer?
White Light Interferometry on VISX Star S2 Spherical Ablations

Without Laser Clean Room System

Tired of Huffing Excimer?
White Light Interferometry on VISX Star S2 Spherical Ablations

100% Vacuum Laser Clean Room System

Courtesy of: University of Arizona
Jim Schweigerling, PhD
Robert Snyder, MD
Data has been published showing that laser and electrosurgical vapors contain viable HPV and HIV DNA. An appropriate smoke evacuator with 0.1 micron or smaller filtration must always be used. To operate without proper smoke evacuation is reckless.


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Excimer Laser ablation of fibroblasts infected with attenuated varicella-zoster virus was performed.

PCR (+)
Virus Culture (-)

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Lack of virus transmission by the excimer laser plume

American Journal Of Ophthalmology
Volume 124, Issue 2, August 1997, Pages 206-211

An excimer laser was used to ablate a virus-infected tissue culture plate. Pseudorabies virus is a porcine enveloped herpesvirus similar in structure and life cycle to human immunodeficiency virus and herpes simplex virus.

Even under conditions designed to maximize the likelihood of virus transmission, the excimer laser ablation plume does not appear capable of transmitting this particular live enveloped virus.
• Polio virus: 30 nm (survive)
• HZV: ≥ 200 nm (not survive)

VENTILATION
General room and local exhaust ventilation (LEV).
Portable smoke evacuators and room suction systems
A capture velocity of about 100 to 150 feet per minute at the inlet nozzle.
A High Efficiency Particulate Air (HEPA) filter or equivalent is recommended for trapping particulates.
Room suction systems can pull at a much lower rate and were designed primarily to capture liquids rather than particulate or gases.

WORK PRACTICES
The smoke evacuator or room suction hose nozzle inlet must be kept within 2 inches of the surgical site to effectively capture airborne contaminants generated by these surgical devices.
At the completion of the procedure all tubing, filters, and absorbers must be considered infectious waste and be disposed appropriately. New filters and tubing should be installed on the smoke evacuator for each procedure. While there are many commercially available smoke evacuator systems to select from, all of these LEV systems must be regularly inspected and maintained to prevent possible leaks. Users shall also utilize control measures such as "universal precautions," as required by the OSHA Blood-Borne Pathogen standard.

• Plume evacuation system (Stackhouse Inc.)
• Mask capable of filtering out small particles (Technol PFR 95 particulate respirator, no. TC-84A-0010, Technol Inc.; no. 4236, filtration efficient 0.1 mm laser plume mask, Johnson & Johnson Medical, Inc.).
• Similar to those suggested for surgeons using the carbon dioxide laser

The Excimer Laser
• Ablative Photodecomposition
  – High Energy (6.4 eV)
  – Irradiance
    • Fluence
    • Measure Of Energy Density
  – Tissue Ablation Threshold
    • 50 mJ/cm²

The Photoablation Process
laser light hits tissue
↓ 10 psec
collagen molecule undergoes conformal change
bound water heats up
↓ 10 nsec
molecules break
↓ 2 μsec
fragments are expelled as plasma
Excimer Laser Ablation Process

Physical Side Effects

- Thermal Damage
  *heat diffusion
  *condensation

- Mechanical Damage
  *direct damage
  *repulsive forces

- Actinic Damage
  *primary radiation
  *secondary radiation

Thermal Damages

The travel time of a heat front for 1 micron in corneal tissue is approximately 5 μsec

Expellation of the 500 °C hot ablation products is completed after approximately 1 μsec

→ The excimer laser is a "cold laser"

Physical Side Effects

- Thermal Damage
  *heat diffusion
  *condensation

- Mechanical Damage
  *direct damage
  *repulsive forces

- Actinic Damage
  *primary radiation
  *secondary radiation

Thermal Damages

The 500 °C hot ablation may condensate at the ablation edges and form the pseudomembrane

Mechanical Damages

- Direct Damage
  Photoablation leads to keratocyte loss (cell death and apoptosis) 100 μm deep. Repopulation within 6 weeks.

- Repulsive Forces
  Photoablation products leave the corneal surface with supersonic speed

→ Repulsive Forces
Mechanical Damages
• Fast Effects of Repulsion
  Pressure transients of up to 100 bar travel through the eye and orbit
• Slow Effects of Repulsion
  Trampoline oscillations of the cornea may lead to central steep islands

Physical Side Effects
• Thermal Damage
  *heat diffusion
  *condensation
• Mechanical Damage
  *direct damage
  *repulsive forces
• Actinic Damage
  *primary radiation
  *secondary radiation

Actinic Damages
• Primary Radiation
  Due to the small penetration depth the 193 nm-light cannot reach the cell nucleus (cytoplasmatic shielding)
• Secondary Radiation
  Secondary radiation has longer wavelengths that can reach the DNA

Actinic Damages
Due to enzymatic repair the threshold of mutagenicity of UV-radiation is approximately $10 \mu W/cm^2$
During a standard PRK, the secondary radiation reaches a level of approximately $5 \mu W/cm^2$

Light Reflection Hazards
• Types of Reflections
  – Specular reflection is a reflection from a mirror-like surface. A laser beam will retain all of its original power when reflected in this manner.
    Note that surfaces which appear dull to the eye may be specular reflectors of IR wavelengths.
  – Diffuse reflection is a reflection from a dull surface. Note that surfaces that appear shiny to the eye may be diffuse reflectors of UV wavelengths.
• Diffuse laser light reflection from a high powered laser can result in an eye injury.

Biology of the Eye

Retinal Hazard Region
The wavelength range of light that can enter the eye is 400 to 1400 nm, though the range that we can actually see is only 400 – 760 nm.
The eye can focus a collimated beam of light to a spot 20 microns in diameter on the retina (called the focal point).
This focusing ability places the retina at risk when exposed to laser light in the wavelength range that will penetrate to the retina, because even fairly low wattage laser light can impact the retina with 100,000 times the radiant power that entered the eye. Because of this optical gain, laser light in the 400 – 1400 nm is referred to as the Retinal Hazard Region.
This is important to remember when working with infrared lasers, because the retina can be injured even though the laser is invisible.

Biological Hazards - Retina
- **Thermal damage** to the retina occurs in the Retinal Hazard Region (from 400 nm – 1400 nm). Thermal damage is not cumulative, as long as the retina cools down between exposures.
- **Photochemical damage** is severe at shorter visible wavelengths (violet & blue) and is cumulative over a working day.
- **Acoustic shock** from exposure to high energy pulsed lasers results in physical tissue damage.

Biological Hazards – Cornea & Lens
- Inflammation injury to the cornea is caused by ultraviolet (UV) wavelengths (200-400 nm). This is the same type of injury that is caused by snow blindness.
- Chronic exposure can cause cataract formation in the lens of the eye just as UV from the sun does.

Laser Hazard Classes
The ANSI Laser Safety standard has defined **Laser Hazard Classes**, which are based on the relative dangers associated with using these lasers.

Class 1 Lasers
This class cannot produce a hazardous beam because it is of extremely low power, or because it has been rendered **intrinsically safe** due to the laser having been completely enclosed so that no hazardous radiation can escape and cause injury.
Class 2 Lasers
- These lasers are visible light (400-760 nm) continuous wave or pulsed lasers which can emit energy greater than the limit for Class I lasers and radiation power not above 1 mW.
- This class is hazardous only if you stare directly into the beam for a long time, which would be similar to staring directly at the sun.
- Because class 2 lasers include only visible wavelengths, the *aversion reaction* will usually prevent us from permanently damaging our eyes. The *aversion reaction* refers to our tendency to look away from bright light.

Class 3a Lasers
- This class of intermediate power lasers includes any wavelength.
- Only hazardous for intrabeam viewing.
- This class will not cause thermal skin burn or cause fires.

Class 3b Lasers
- Visible and near-IR lasers are very dangerous to the eye.
- Pulsed lasers may be included in this class.
- This class will not cause thermal skin burn or cause fires.
- Requires a Laser Safety Officer and written Standard Operating Procedures.

Class 4 Lasers
- These high-powered lasers are the most hazardous of all classes.
- Even a diffuse reflection can cause injury.
- Visible and near-IR lasers will cause severe retinal injury and burn the skin. Even diffuse reflections can cause retinal injuries.
- UV and far-IR lasers of this class can cause injury to the surface of the eye and the skin from the direct beam and specular reflections.
- This class of laser can cause fires.
- Requires a Laser Safety Officer and written Standard Operating Procedures.

Maximum Permissible Exposure (MPE)
- The Maximum Permissible Exposure (MPE) is the highest level of radiation to which a person can be exposed without hazardous effects.
- The MPE is specified in W/cm² for continuous wave lasers and in J/cm² for pulsed lasers. The value depends on wavelength, exposure duration and pulse repetition frequency.
- Exposure to radiation levels in excess of the MPE will result in adverse biological effects, such as injury to the skin and/or eyes.

Nominal Hazard Zones (NHZ)
- The *Nominal Hazard Zone* (NHZ) is the location around the laser within which a person can be exposed to radiation in excess of the MPE.
- When Class 3b and 4 lasers are unenclosed, the Laser Safety Officer must establish a NHZ.
- People may be injured if they are within the perimeter of this zone while the laser is in operation.
Non-Beam Hazards

Non-beam hazards refer to anything other than the laser itself that can create a hazard. This type of hazard includes:

- Electrical Hazards
- Fire Hazards
- Laser Generated Air Contaminants (LGAC)
- Compressed Gases
- Chemical Hazards
- Collateral and Plasma Radiation
- Noise

Non-Beam Hazards – Electric Shock and Fire

- **Electric Shock**
  Use caution when working on or near the high-voltage power supplies used for high-power Class 3 and 4 lasers; there is sufficient voltage in these power supplies to injure or kill.

- **Fire**
  High powered Class 4 lasers will easily ignite flammable materials (such as paper or flammable liquids). You must have a fire extinguisher if you have a class 4 laser. In some circumstances, Class 3 lasers could also ignite flammable liquids.

Laser Generated Air Contaminants (LGAC)

- Air contaminated due to interaction of laser beam with target material can result in the production of toxic chemicals.
- During surgical procedures, biohazardous aerosols containing bloodborne pathogens are created.
  - The OSHA web site provides information on biohazardous air contaminants produced during surgery. To prevent personnel from inhaling the LGAC and to prevent the release of LGAC to the environment, exhaust ventilation with special filters may be needed.
- If you are concerned that hazardous air contaminants may be generated by your laser, contact VEHS.

Chemical Hazards

Lasers use a variety of lasing mediums, and some of these are comprised of toxic chemicals, such as dyes, solvents and hazardous gases.

- Many laser dyes and solvents are toxic and carcinogenic.
- A few of the hazardous gases which may be part of your lasing system include chlorine, fluorine, hydrogen chloride and hydrogen fluoride. Please contact VEHS for assistance with the special ventilation precautions required for these gases.
- As with all hazardous chemicals, you should review the Material Safety Data Sheet (MSDS) for the chemicals which are used in or around your laser. Please take the Safety & Environmental Protection in the Chemical Laboratory course if you are using hazardous chemicals in your lab.

Compressed Gases

Please take the Lab Safety Module on Compressed Gas Safety if you are working with laser systems which utilize compressed gases.

Collateral & Plasma Radiation

- **Collateral radiation** refers to radiation that is not associated with the primary laser beam. This collateral radiation may be produced by power supplies, discharge lamps and plasma tubes. This radiation can be any type of EM radiation, from x-rays to radio waves.

- High powered lasers can also produce **Plasma Radiation** from the interaction of the laser beam with the target material, especially when these lasers are used to weld metals. Plasma radiation may contain enough UV and/or blue light to require additional protective measures.
Noise

- Noise generated by the laser system that is at 90 decibels or higher requires hearing protection.
- If you have reason to believe that your laser is creating a hearing hazard during operation, VEHS can perform noise level monitoring to determine whether or not the noise associated with your laser is at this level.

Non-Beam Hazards - Chemicals

Hazardous chemicals used as part of the lasing medium can create special problems.

- Dyes and solvents used in dye lasers are toxic and often carcinogenic and therefore must be handled with care. Make sure laser operators are familiar with the Material Safety Data Sheets for these chemicals.
- Toxic gases, such as HF and halogens commonly used for excimer lasers, will require special cabinets and air handling to prevent exposure to laser operators and release of toxic gases to the environment.

Control Measures

- There are several measures that can be taken to prevent injury from lasers. These measures include:
  - Engineering Controls
  - Administrative Controls
  - Personnel Protective Equipment
  - Warning Signs and Labels

Engineering Controls

- Engineering controls are measures that are incorporated into the laser system and are designed to prevent injury to personnel. Engineered safety controls are preferable to PPE or Administrative controls.
- Examples include
  - Protective housings
  - Interlocks on Removable protective housings
  - Service access panels
  - Key control master switch (Class 3b & 4)
  - Viewing Windows, Display Screens, Collecting Optics
  - Beam path enclosures
  - Remote interlock connectors (Class 3b & 4)
  - Beam Stop or attenuator (Class 3b & 4)

Administrative Controls

Administrative controls are procedures that are designed to prevent personnel from injury. Examples of administrative controls required for Class 3b & 4 lasers include:

- Designation of Nominal Hazard Zones (NHZ).
- Written Standard Operating Procedures (SOP’s) which are enforced by the Laser Safety Officer.
- Warning signs at entrances to room.
- Training for all personnel who will be operating the laser or in the vicinity of the laser while it is in operation. (Training is also required for those using Class 2 and 3a lasers.)
- Allow only authorized, trained personnel in the vicinity of the laser during operation.

PPE for Skin

Personnel Protective Equipment (PPE) for Skin exposed to Class 3b or 4 lasers:

- Ultraviolet lasers and laser welding/cutting operations may require that tightly woven fabrics be worn to protect arms and hands. Sun screen may also be used to provide some additional protection.
- For lasers with wavelengths > 1400 nm, large area exposures to the skin can result in dryness and even heat stress.
PPE for Eyes

- PPE is not required for class 2 or 3a lasers unless intentional direct viewing > 0.25 seconds is necessary.
- Personnel Protective Equipment (PPE) for eyes exposed to Class 3b or 4 lasers is mandatory. Eyewear with side protection is best. Consider these factors when selecting eyewear:
  - Optical Density (OD) of the eyewear
  - Laser Power and/or pulse energy
  - Laser Wavelength(s)
  - Exposure time criteria
  - Maximum Permissible Exposure (MPE)
  - Filter characteristics, such as transient bleaching

Protect Your Eyes!

In a fraction of a second, your vision can go dark.

Other PPE

PPE may also be required to provide protection from hazardous chemicals and gases. Consult with VEHS if you need assistance with determining the appropriate PPE for use with your laser.

Warning Labels

Only Class 1 lasers require no labels. All other lasers must be labeled at the beam’s point of origin.

- Class 2:
  "Laser Radiation – Do Not Stare into Beam."
- Class 3a:
  "Laser Radiation – Do not Stare into Beam or View Directly with Optical Instruments."
- Class 3b:
  "Laser Radiation – Avoid Direct Eye Exposure."
- Class 4:
  "Laser Radiation – Avoid Eye or Skin Exposure to Direct or Scattered Radiation."

Warning Signs

All rooms with class 3a, 3b or 4 lasers must have appropriate signs posted at all entrances. Signs must:

- Warn of the presence of a laser hazard in the area
- Indicates specific laser safety policies
- Indicates the relative hazard such as the Laser Class and the location of the Nominal Hazard Zone
- Indicates precautions needed such as PPE requirements for eyewear, etc.

Laser Warning Signs

- “DANGER” indicates a very dangerous situation that could result in serious injury or death. This sign should be used for Class 3b and 4 lasers.
- “CAUTION” indicates a potentially hazardous situation which could cause a less serious injury. This sign should be used for Class 2 and 3a lasers.
- “NOTICE” does not indicate a hazardous situation. This sign should only be used to make people aware of facility policies regarding laser safety and/or to indicate that a repair operation is in progress.
**“CAUTION” Warning Sign**

Safety Instructions may include:
- Eyewear Required
- Invisible laser radiation
- Knock Before Entering
- Do Not Enter When Light is On
- Restricted Area

**“DANGER” Warning Sign**

Safety Instructions may include:
- Eyewear Required
- Invisible laser radiation
- Knock Before Entering
- Do Not Enter When Light is On
- Restricted Area

**“NOTICE” Sign for Laser Repair**

Safety Instructions may include:
- Eyewear Required
- Invisible laser radiation
- Knock Before Entering
- Do Not Enter When Light is On
- Restricted Area

**Additional Warnings for 3b & 4 Lasers**

- The Nominal Hazard Zone (NHZ) must be marked so that the boundary of the NHZ is clearly defined.
- An audible alarm, warning light or a verbal “countdown” is required before activation.
- A visible warning light should flash when the laser is in operation and the light should be readily visible through protective eyewear.

**Leading Causes of Laser Accidents**

- Unanticipated eye exposure during alignment
- Available eye protection not used
- Equipment malfunction
- Improper methods for handling high voltage (This type of injury has resulted in death.)
- Inadequate training
- Failure to follow SOP
- Failure to provide non-beam hazard protection.
- Equipment improperly restored following service
- Incorrect eyewear selection and/or eyewear failure

**Medical Surveillance**

- Medical surveillance is required for individuals who work with or around Class 3b and 4 lasers.
- Contact the Vanderbilt Occupational Health Clinic (OHC) if you need a medical evaluation.
  - OHC Phone: 6-0955
  - OHC Web Site: [http://www.vanderbilt.edu/HRS/wellness/occhealth.htm](http://www.vanderbilt.edu/HRS/wellness/occhealth.htm)