Principles of Laser Safety

and the uOttawa Laser Safety Program

September 20, 2016

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Risk Management Specialist (Laser/X-Ray)

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What is Laser Safety?

- Signs?
- Permits?
- Warning lights?
- Goggles?

- What do you ask yourself before entering?
What is Laser Safety?

The person most likely to care about your safety is you

Do I understand the safety measures?

Where do I go if I have questions?

Do I need to be here right now?

Is there a better way to do that?

Safety Starts Here
Responsibility

The ultimate responsibility in the safe use of lasers in any environment falls completely on the user.

YOU are responsible to ensure all hazards are contained.

YOU are responsible to ensure beams do not pose a hazard to others.

YOU are responsible to ensure your actions do not harm others.
Learning Objectives

1. Identify laser components, properties and classifications
2. Understand how an eye images light
3. Recognize how lasers injure the eye and skin
4. Develop engineering & administrative laser controls
5. Follow the uOttawa Laser Safety Program and ANSI Z136.1
6. Familiarize yourself with non-beam hazards
7. Evaluate laser eyewear needs
Common Types of Lasers

HeNe

Nd:YAG

Carbon Dioxide

Ti:Sapphire

Diode/Semiconductor

Fibre *

* "Supercontinuum in a microstructured optical fiber" by I, Blinking Spirit. Licensed under CC BY-SA 3.0 via Wikimedia Commons - http://commons.wikimedia.org/wiki/File:Supercontinuum_in_a_microstructured_optical_fiber.PNG#media/File:Supercontinuum_in_a_microstructured_optical_fiber.PNG
The Electromagnetic Spectrum

X-Ray Lasers
news.slac.stanford.edu/features/growth-spurt-x-ray-lasers

Retinal Hazard Region
Main components of a Laser

**EXCITATION MECHANISM**
- Optical
- Electrical
- Chemical

**ACTIVE MEDIUM**
- Solid (Crystal, Diode)
- Liquid (Dye)
- Gas

**OPTICAL RESONATOR**
- HR Mirror and Output Coupler

Excitation Mechanism (Pump)
- Excites atoms to higher energy state.

Active Medium (Gain, Amplifier)
- Contains atoms that emit light by stimulated emission.

Optical Resonator
- Reflects laser beam through the active medium for amplification.
What is Stimulated Emission?

Step 1: Absorption

- Relaxed Atom
- Pump Photon (or other stimulus)

Step 2: Emission

- Excited Atom
- Incident Photon
- Stimulated Photon
  - same wavelength
  - same direction
  - in phase
Characteristics of a Laser Beam (Coherence)

- Low divergence
  - highly directional
  - small focal spot

- High Brightness
  - High power density
  - Short pulses

- Monochromatic
  - narrow spectrum a better term

This combination makes laser light focus 100 times better than ordinary light
Beam Divergence

Far-field measurement:
ex: 1 foot diameter beam ($d$) on a wall 1000 feet away ($r$), divergence angle ($\phi$) is:

$$\phi = \frac{d}{r} \quad \text{(Eq.1)}$$

$$\phi = \frac{1 \text{ ft}}{1000 \text{ ft}} = 0.001 \text{ radian} = 1 \text{ mrad}$$
Beam Divergence

Incoherent source:

- Sphere: $4\pi$ steradians
- Power spread over large area
- Drops as $r^2$ with distance
Why a laser pointer is a borderline ocular hazard

Beam Intensity

Irradiance = \( \frac{\text{Power}}{\text{Area}} \)

**IRRADIANCE AT LENS:**

\[ E_1 = \frac{5 \text{ W}}{\pi (0.5 \text{ cm})^2} \]

\[ E_1 = 6.4 \frac{\text{ W}}{\text{ cm}^2} \]

**IRRADIANCE AT FOCAL SPOT:**

\[ E_2 = 64 \frac{\text{ kW}}{\text{ cm}^2} \]

The diameter is reduced by a factor of 100; The irradiance is increased by a factor of 10,000.
Sun Intensity

- Sun emits $3.826 \times 10^{26}$ W into $4\pi$ steradians
- Verify with Stefan-Boltzmann Law:
  
  \[ P = \epsilon \sigma A T^4 \]

  where:
  - $T = 5770$ K
  - $R_s = 6.96 \times 10^8$ m
  - $\sigma = 5.67 \times 10^{-8}$ W m$^{-2}$ K$^{-4}$

  \[ P = (1)(5.67)4\pi(6.96)^2(5770)^4 \times 10^8 \]
  \[ P = 3.83 \times 10^{26} \text{ W} \]

  \[ E = \frac{P}{A} = \frac{3.83 \times 10^{26}}{4\pi (1.46 \times 10^{13})} \text{ W/cm}^2 \]

  \[ E = 0.143 \text{ W/cm}^2 \]

**Beam Intensity**

- Ti:S oscillator beam: 2 mm diameter ($e^{-1}$), 20 nJ pulse energy, and a 30 fs pulse width (FWHM)
  - The irradiance is:

\[
E_{avg} = \frac{P}{\pi w^2} = \frac{Q}{\tau_{FWHM} \pi w^2} \frac{1}{1}
\]

(Eq.2 again)

Note: this laser operates at 80 MHz; in 0.25 s you would take in 20 million of these pulses!!
Incoherent vs. Laser Sources

The “microscopic” view

Incoherent: random

Laser: “in phase”

Pulsed Laser: All these photons concentrated in extremely small time span

\[ \Delta t \]
Laser Classifications of Lasers

• Hazards
  – Increase with laser intensity
  – Classification system categorizes increasing hazard

• Classification
  – Based on accessible level of laser radiation during normal operation

• Classification made by manufacturer
Class 1

Nd:YAG Laser Marker

- Safe during normal use
- Incapable of causing injury
- Low power or enclosed beam

Label not required

May be higher class during maintenance or service

AEL less than or equal to MPE
Class 2

- Staring into beam is an eye hazard
- Eye protected by aversion response
- Visible lasers only (400 – 700 nm)
- CW maximum power 1 mW

AEL less than or equal to MPE for visible lasers and ¼ sec exposure

Label not required
May be higher class during maintenance or service
Class 1M and 2M

M is for magnification

A class 1M laser is class 1 unless magnifying optics are used.

A class 2M laser is class 2 unless magnifying optics are used.

M classes usually apply to expanded or diverging beams.

Condition 1
Expanded Beam

Condition 2
Diverging Beam
Class 3R (Formerly IIIa)

- Aversion response not adequate eye protection
- CDRH includes visible lasers only
- ANSI includes invisible lasers
- CW max power (visible) 5 mW

1 to 5X AEL Class 1 (invisible) < 5X AEL Class 2 (visible)
Class 3B

- Direct exposure to beam is eye hazard
- Visible or invisible
- CW maximum power 500 mW

DPSS Laser with cover removed

AEL exceeds Class 3R but less than 500 mW (CW)

Class 4

- Exposure to direct beam & scattered light is eye and skin hazard
- Visible or invisible
- CW power above 500 mW
- Fire hazard

Photo: Keith Hunt - www.keithhunt.co.uk
Copyright: University of Sussex, Brighton (UK)

AEL exceeds Class 3B
# Laser Classifications

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Incapable of causing injury during normal operation</td>
</tr>
<tr>
<td>1M</td>
<td>Incapable of causing injury during normal operation unless collecting optics are used</td>
</tr>
<tr>
<td>2</td>
<td>Visible lasers incapable of causing injury in 0.25 s.</td>
</tr>
<tr>
<td>2M</td>
<td>Visible lasers incapable of causing injury in 0.25 s unless collecting optics are used</td>
</tr>
<tr>
<td>3R</td>
<td>Marginally unsafe for intrabeam viewing; up to 5 times the Class 2 limit for visible lasers or the Class 1 limit for invisible lasers</td>
</tr>
<tr>
<td>3B</td>
<td>Eye hazard for intrabeam viewing, usually not an eye hazard for diffuse viewing</td>
</tr>
<tr>
<td>4</td>
<td>Eye and skin hazard for both direct and scattered exposure</td>
</tr>
<tr>
<td>Laser Classification Language</td>
<td></td>
</tr>
<tr>
<td>------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>1</strong></td>
<td>No signage needed. May have Class 3B or 4 language on protective housings if embedded.</td>
</tr>
<tr>
<td><strong>1M</strong></td>
<td>No signage</td>
</tr>
<tr>
<td><strong>2</strong></td>
<td>CAUTION : Do Not Stare Into Beam</td>
</tr>
<tr>
<td><strong>2M</strong></td>
<td>CAUTION : Do Not Stare Into Beam or View Directly with Optical Instruments</td>
</tr>
<tr>
<td><strong>3R</strong></td>
<td>WARNING : Avoid Direct Eye Exposure to Beam</td>
</tr>
<tr>
<td><strong>3B</strong></td>
<td>WARNING : Avoid Direct Eye Exposure to Beam</td>
</tr>
<tr>
<td><strong>4</strong></td>
<td>WARNING / DANGER : Avoid Eye and Skin Exposure to Direct or Scattered Radiation</td>
</tr>
</tbody>
</table>
Optics and the Eye
Optics: Focusing in the Eye

- Cornea does most of the focusing
  - fixed focal length
- Lens adjusts for distance

\[ h_i = 17 \text{ mm} \times \theta_{source} \]
Optics: Focusing in the Eye

Parallel rays

Point focus on central vision

$\theta < 1.5$ mrad is a point source for the eye

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Laser Compliance Specialist ext. 2000
Optics: Focusing in the Eye

$\theta < 1.5$ mrad is a point source for the eye
Incoherent Light vs. Laser: Power

- Light bulb power (60 W) is **Electrical** not **Optical**
  - Laser rated in optical power
  - Tungsten bulb: 16 lumens/W

- **Lumen??**
  - Eye’s response to *visible* light
  - 683 lumens is 1 W of optical power

- 60 W tungsten filament bulb about 1.4 W (optical)
  - 2 % conversion efficiency

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Response</th>
</tr>
</thead>
<tbody>
<tr>
<td>475 nm</td>
<td>0.1535</td>
</tr>
<tr>
<td>515 nm</td>
<td>0.6206</td>
</tr>
<tr>
<td>556 nm</td>
<td>0.999</td>
</tr>
<tr>
<td>570 nm</td>
<td>0.9733</td>
</tr>
<tr>
<td>630 nm</td>
<td>0.298</td>
</tr>
<tr>
<td>680 nm</td>
<td>0.0181</td>
</tr>
</tbody>
</table>
Example: How much light enters the eye

Standing 50 cm from a 6 cm tall 60 W light bulb and a 1 mW laser pointer with a 2 mm beam diameter.

1. How much light enters your eye?

\[
\frac{1.4 \text{ W}}{4\pi \text{ sr}} = 0.11 \frac{\text{W}}{\text{sr}}
\]

3.3 \(\mu\text{W}\) enters eye \((2 \times 10^{-4} \%)\)
Example: How much light enters the eye

Standing 50 cm from a 6 cm tall 60 W light bulb and a 1 mW laser pointer with a 2 mm beam diameter.

1. How much light enters your eye?

1 mW enters your eye (100 %) 300X more power
Example: Light concentration

Standing 50 cm from a 6 cm tall 60 W light bulb and a 1 mW laser pointer with a 2 mm beam diameter.

2. How concentrated is the light on the retina?

Bulb is a 2 mm image (assume circular diameter)

\[ E = \frac{3.1 \ \mu W}{\pi (0.1 \text{ cm})^2} = 0.1 \text{ mW/cm}^2 \]

Laser focuses to 10 µm spot (conservative guess)

\[ E = \frac{1 \text{ mW}}{\pi (5 \times 10^{-4} \text{ cm})^2} = 1.3 \text{ kW/cm}^2 \]

Laser pointer power density is a million times higher on your retina.
Eye: Colour Response

- Response to different wavelengths
- Green pointers do not need to be 5x more powerful!

http://www.cvrl.org/cvrlfunctions.htm
(2 deg. Luminous efficiency function)
But how well do you know your laser pointer?

- Green colour
  - but how?

- Power < 5 mW
  - okay, but...kind of bright...?
  - red laser pointers are only 1 mW and they work fine...

see recent FDA video:  www.youtube.com/watch?v=FPPnFg_ujJI
But how well do you know your laser pointer?

- Green colour
  - second harmonic generation
- The IR is 7x brighter!

\[
532 \text{ nm} = \frac{1064}{2} \text{ nm}
\]
But how well do you know your laser pointer?

- Green colour
  - second harmonic generation
- The pump light leaks through, also

- IR Filter
- 1064 nm gain medium
- Doubling crystal (532 nm)
- 810 nm pump laser
Laser Injuries
Risk

Probability of laser injury: Product of probability of laser exposure and amount exposure exceeds the injury threshold

\[ P(\text{Laser Injury}) = P(\text{Exposure}) \times \text{Impact} \]

Need countable instances, but can enumerate:

<table>
<thead>
<tr>
<th>Causes of Exposure</th>
<th>Improvement Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Uncontrolled beams</td>
<td>Horizontal, below waist, clamped optics, covered beams, dumped</td>
</tr>
<tr>
<td>Misfire</td>
<td>Beam blocks, redundant controls (microscopes)</td>
</tr>
<tr>
<td>Behaviours</td>
<td>SOPs, Respect Risks</td>
</tr>
</tbody>
</table>

(Also apply to non-beam hazards)
Risk

Probability of laser injury: Product of probability of laser exposure and amount exposure exceeds the injury threshold

\[ P(\text{Laser Injury}) = P(\text{Exposure}) \times \text{Impact} \]

Need countable instances, but can enumerate:

<table>
<thead>
<tr>
<th>Exceed Injury Limit</th>
<th>Improvement Strategies</th>
</tr>
</thead>
<tbody>
<tr>
<td>Excessive power level</td>
<td>Reduce power during alignment, use other lasers</td>
</tr>
<tr>
<td>Improper PPE</td>
<td>Wear goggles, wear lab coat, evaluate goggle need</td>
</tr>
</tbody>
</table>

(Also apply to skin hazards)

You likely have a higher tolerance for your voluntary use of research-grade lasers as compared to general public who walks by the lab door
Causes of Laser Accidents

Eye Injury
Eye Injury
The Human Eye

Laser Safety
- ¼ second blink rate
- 7 mm dark-adapted iris diameter
- 10 s fixed gaze limit (saccadic movement)
  - factor in blue-light/UV dose
Types of Laser Eye Exposure

- **INTRABEAM VIEWING**
  - Laser beam directly enters the eye.

- **SPECULAR REFLECTION**
  - Laser beam reflects off a mirror and back to the eye.

- **DIFFUSE REFLECTION**
  - Laser beam scatters off a rough surface and back to the eye.

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Wavelength Dependent Effects

- 3 vulnerable ocular structures (absorbs at different wavelengths):

  **Cornea:**  UV, mid-IR & far-IR  (burns, opacity)
  **Lens:**  near-UV & near-IR  (cataracts)
  **Retina:**  visible & near-IR  (burns, lesions)

**Retina** is most vulnerable
- absorbs at common laser wavelengths
- light $100,000 \times$ more intense than at cornea
Lasers harm eyes because:

- Focused to nearly a spot by the eye
  - Retina and macula (fovea)
  - increases laser power density by 100,000
  - 1 mW/cm² becomes 100 W/cm²

- Focuses visible and infrared radiation
  - you can’t see infrared

- A 0.5 mJ pulse can cause permanent retinal damage
  - blindness if central vision affected
  - Retina can repair some damage
Example: Retinal Injury

• Several hours aligning low-power 532 nm Nd:YAG through a dye laser
  – Not wearing goggles to see beam

• A 10 ns, 20 nJ pulse focused onto fovea
  – Green flash: no pain
  – Not immediately aware of eye damage

• Noticed blind spot like a camera flash in right eye after returning to desk
  – 5.00 pm Friday: didn’t report incident
  – Saturday afternoon: knew a problem existed
Example: Retinal Injury

Ph.D. student, Ti:S compressor
Example: Retinal Injury
Example: Multiple Pulse Retinal Injury

- Partial reflection of 10 ns, 6 mJ Nd:YAG
  - no goggles
- Beam struck eye
  - Distinct popping sound
  - Laser-induced explosion at back of eyeball
- Vision obscured by blood streams in vitreous humour
  - Viewing through fishbowl with mix of glycerine, blood and black pepper
- Most immediate response is horror then going into shock
Example: Multiple Pulse Retinal Injury
Pulsed Laser-Matter Interaction

- Damage mechanism varies with pulse duration
  - continuous beam - 50 ns
    - charring/blistering of tissue
  - 50 ns - 1 ps
    - shock wave formation and tissue liquification
    - tissue ejected into vitreous humour (floaters)
  - 1 ps - 1 fs
    - multiphoton ionization of tissue
    - ejection of individual nuclei/small clusters
Summary on Retinal Injury

• Retinal Injuries (blindness) are **permanent**

• Retina contains:
  - Fovea
    • central colour vision
    • depth perception in 3° cone
    • enables reading, driving, etc.
  - Optic Nerve
    • central nerve bundle of an eye
    • damage can lead to total loss of vision
  - Blood Vessels
    • rupture leads to blood in vitreous humour

**Conclusion:**
A single retinal lesion can lead to severe visual impairment!
Laser Radiation as a Skin Hazard

- Thermal Injury (burn)
- Erythema (sun burn)
- Epidermis: melanin inactivates free radicals made at UV
- Accelerated ageing and pigmentation

Some people may be more at risk of photosensitive reactions from genetics or induced by medicines
Example: Skin Irradiation

- XeCl (308 nm) excimer laser
- Laser enclosure opened to look for an electrical short inside the laser chamber
- Struck in neck by several 15 mJ pulses
  - did not feel anything until hours later
  - four burns appears on his neck
  - Took three weeks to heal
- Wore eye protection
  - eyes were unaffected

www.uottawa.ca/services/ehss/EMR.html

ACGIH TLV for UV Exposure Limits
Example: Skin Irradiation

![Skin Irradiation Example](image1)

![Skin Irradiation Example](image2)
BREAK
Laser Safety Program at uOttawa

- Individuals
- Office of Risk Management/RadBio Safety Group
  - Assistance/Guidance
  - Permits
  - Education and Training
  - Inspections/Accidents/Incidents Follow-up
- Department/Faculty
  - Ensure lasers used in accordance with our standards
Who makes the laser rules?

The following regulatory bodies:

- Ontario Ministry of Labour (MOL) and the Occupational Safety and Health Administration (OSHA) recognizes the American National Standard for Safe Use of Lasers (ANSI Z136.1) as part of our General Duties and Due Diligence (www.labour.gov.on.ca/english/hs/topics/radiation.php)
- also in Canada OHS Regulation (SOR/86-304 (10.26(I))
- US Federal Laser Product Performance Standard (FLPPS) of the Center for Devices and Radiological Health (CDRH)
- International Electrotechnical Commission (IEC 60825-1)
- Canadian Standards Association (CSA-Z386): Health Care Facilities
• Defines classification of lasers by accessible energy
• Defines LSO roles (App.A)
  – Expected level of previous expertise
• Defines laser safety program structure (App.A)
  – Track lasers
  – Train users
• Control of Laser Areas by classification
Laser technology has dramatically evolved since its conception in 1917, to the development of the first laser in 1960; and now to its expanding applications. Currently, lasers are used in such diverse areas as research, telecommunication, industry, medicine, entertainment and commercial products. The risk associated with laser use varies from minimal to potentially significant depending upon the characteristics of the laser and the design of the laser system.

The University of Ottawa has mandated the Radiation Safety Committee and the Office of Risk Management to ensure the appropriate measures are in place to address any potential risks. The Laser Safety Program is managed by the Assistant Director, Radiation and Biosafety (Lois Riedman-Plunket), and the Laser and Non-Ionizing Radiation Compliance Specialist (Gwen Kirkwood). It is designed to assist in minimizing the associated risk of laser use.

This web page has been designed as an educational tool and to provide direction to users as to the University’s standards and those found in industry.

### Researcher’s Corner
- Laser Permit Form
- Laser User Form
- Training Requirements
- Presentation
- Moving/Shutting Down Lab

### Laser Safety Eyewear
- How to choose the right one?

### Specific Topics
- Biological Effects
- Control Measures
- Classification of Lasers
- Femtosecond Laser Technology, Safety Aspects
- Hazard Evaluation
- Laser Printers
- Laser SOP Template
- Laser, signage and Labelling
- Laser Plumes
- LED vs Laser Diode

### External Links
- Quebec Photonics Network
- Agile All-Photonics Networks
- Canadian Photonics Industry Consortium (PhotonicsCanada)
- Canadian Centre for Occupational Health and Safety

### Regulatory
- Ontario Ministry of Labour

### Free Software
- EasyHAZ (Kentek)

### Associations
- IEEE Photonics Society
- International Laser Display Association
- Laser Institute of America
- Canadian Radiation Protection Association (CRPA)
- International Radiation Protection Association (IRPA)

[orm.uottawa.ca/programs/laser-safety](orm.uottawa.ca/programs/laser-safety)

- Updated Winter 2015
- Bookmark it
- Refer to it
- Bilingual
Lasers are electromagnetic waves (radiation)
- EMR
- hazards are wavelength dependent
- more info here

Bookmark it
Refer to it
Bilingual
CONTROL OF LASER HAZARDS
How do we reduce risk?

Laser Control Measures: **shall** be devised to reduce the possibility of exposure of the eye and skin to hazardous levels of laser radiation – ANSI Sec. 4.1.

- **Engineering Controls (Beam hazard control)**
  - barriers/curtains, warning device, beam blocks, protective housing (with interlocks), key control

- **Administrative and Procedural Controls**
  - SOPs, training, appropriate signage, laser registration (permit)

- **Protective Equipment**
  - eyewear, lab coats
Laser Hazard Evaluation

MPE – Maximum permissible exposure
Laser radiation level up to which a person may be exposed without hazardous effects

NHZ – Nominal Hazard Zone
Where direct, reflected or scattered radiation during normal operation exceeds MPE

LCA – Laser Controlled Area
Where beams are deliberately contained to limit the NHZ
Individual Responsibility

• Ensure you are an authorized user
• Have your name on the uOttawa laser permit
• Follow appropriate training
• Take reasonable precautions to ensure your safety and that of others
• Performed laser tasks in a manner that minimizes radiation exposure
• Do not initiate or participate in any activity that may endanger the health or safety of anyone

The person operating the laser always has the primary responsibility for all hazards associated with laser use
PRIORIT #1
Engineering Controls

CONTROL OF LASER HAZARDS
Indoor Laser Controlled Area

Shields public from inadvertent exposure to laser radiation and associated non-beam hazards

Not compliant: A room without shield to public

Compliant: protects public, PPE, warning lights

Best: Compliant, and reduces hazard to users
Curtains and Barriers (Room)

Photos courtesy of KENTEK

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Enclosures and Controls

- Protective Housing (if has interlocks)
  - curtains/barriers or enclosure otherwise

- Key control (with master switch)
- Laser area warning signs
- Activated warning system (illuminated or audible)
# ANSI Enclosure Definitions

<table>
<thead>
<tr>
<th>Protective Housing</th>
<th>Enclosure</th>
</tr>
</thead>
<tbody>
<tr>
<td>- Interlocked or tool entry enclosure</td>
<td>- No interlocks</td>
</tr>
<tr>
<td>- Required for Class 3B and 4 lasers</td>
<td>- Considered barrier or curtain</td>
</tr>
<tr>
<td>- Embedded lasers (Class 1 designation)</td>
<td>- Removable panels labeled with laser classification language</td>
</tr>
<tr>
<td>- Fail-safe interlocks ideal</td>
<td></td>
</tr>
</tbody>
</table>

**FULLY ENCLOSED BEAM PATH**

![Diagram of a fully enclosed beam path](image)

- Requires interlocks

**LIMITED OPEN BEAM PATH**

![Diagram of a limited open beam path](image)

- Some scattered light escapes
- NHZ is small
Barriers and Enclosures
PRIORITY #2
Administrative and Procedural Controls

CONTROL OF LASER HAZARDS
Administrative and Procedural Controls

- Education and Training
  - User tracking
  - Spectators/Visitor rules

- Standard Operating Procedures (SOPs)
  - Laser Tracking and Permitting
  - Laser On/Off, Alignment, Training

- Signage
Laser Training and uOttawa Safety

- Class 3B and Class 4 lasers have highest hazard
  - User training required (practical and theoretical)
  - Danger signs and other control measures
  - User tracking

- Training
  - This class is a theoretical baseline for all users
  - Practical training covers in-lab issues (very important)
  - Refresher Training every 4 years
Laser Permits And User Tracking

Your supervisor (permit holder)
Lab supervisor
Open Class 3B / 4 Laser Info

Year-DEPT-MMDD issued

Expiry Date
- Refresher
- Inspections
- Record review

Office of Risk Management
Laser Compliance Specialist ext. 2000
**LASER USER REGISTRATION FORM**

**Return to:** Laser Compliance Specialist
Office of Risk Management
1 Nicholas Street, Suite 840
Ottawa, ON K1N 7B7
Phone: (613) 562-5800 x2000  Fax: (613) 789-5711

### Laser User Information:
- **Surname:**
- **First Name:**
- **Faculty:**
- **Department:**
- **Telephone:**
- **Building:**

### Supervisor (Permit Holder) Information:
- **Surname:**
- **First Name:**
- **Position:**
- **Lab Supervisor:**

### SECTION 1: INFORMATION ON LASERS YOU WILL BE USING
**When do you expect to start working with lasers?**
- [ ] Already Started
- [ ] Now
- [ ] 0-3 Months
- [ ] 3-6 Months
- [ ] >6 Months
- [ ] Never

**Lab Building:**
- **Room:**
- **Permit #:**
- **Laser (Do/Not Permit):**

**Laser class:**
- [ ] Open Beam
- [ ] Embedded Beam

**Wavelengths:**

### SECTION 2: RISK MITIGATION
Please describe your experimental techniques, strategies and procedures that you will use to mitigate the risk to yourself and others during your use of the laser listed above. Take this opportunity to think about all possible hazards (beam and non-beam) introduced by your proposed use of the laser.

- [ ] A new or existing experimental setup?
- [ ] New
- [ ] Existing

**Will other lasers be operating at the same time as your laser?**
- [ ] Yes
- [ ] No

If yes, will you be working alone with others/supervision?
- [ ] Yes
- [ ] No

**What protective equipment or products will you use?**
(Include any details)

**What hazards does your experiment introduce?**
(Consider both beam and non-beam hazards)

**Briefly describe or provide the Standard Operation Procedures (SOPs) you will require and follow in your use of this laser**

---

**Office of Risk Management**
Laser Compliance Specialist ext.2000
- Interim training
- Previous training
- This training

**In-Lab Training**
What have you been taught by the lab supervisor?
- Optics handling
- Beam handling
- Hazardous material
- Emergencies
- Laser Maintenance
  -- I want to know who is manipulating/servicing Class 4 lasers

*Brief, descriptive Most important*
### Permit holder

- Identify the laser uniquely
- Laser parameters to assess hazard and PPE

---

**Laser information**

1. Manufacturer
2. Model No.
3. Serial No.
4. Building/Room #
5. Laser Type
6. Laser Class

---

**SECTION 2: LASER OPERATING PARAMETERS**

<table>
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</table>

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*pg. 1*
SOPs

• Laser Turn On/Off/Emergency Procedure

• Beam handling/Alignment Procedure
  – How do you steer from optic to optic?
  – How do you visualize it (cards/viewers)?

• Training Procedure
  – Routine in-lab training (User Form)
  – Steps to achieve authorization

• Hazardous material
  – MSDS location, handling, disposing, cleaning spills
  – Optical fibres
SOPs Can Include:

Description of laser
- Type and wavelength; intended application & location
- Average power, energy per pulse, pulse duration, rep. rate

*Why? In case procedure is specific to laser*

Non-Beam Hazards
- Electrical hazards, LGAC, other
- *Spill control*

Control Measures – List for each hazard:
- Eyewear requirement; wavelength and OD
- Description of controlled area and entry controls
- Reference to equipment manual
Suggested SOP Format

Standard Operating Procedures

<table>
<thead>
<tr>
<th>Manufacturer</th>
<th>Maker</th>
<th>Model</th>
<th>YLS</th>
<th>Serial</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Fibre laser</td>
<td>Class</td>
<td>4</td>
<td>Max Power</td>
</tr>
<tr>
<td>Location</td>
<td>CBY B123</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Emergency Contact</td>
<td>Type name and telephone # of Sublicensee for this instrument here</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Write a statement that operation of this system is restricted to authorized and trained users as indicated on the permit (permit location written here).

Training Protocol

For new users of the system, list the steps an authorized and fully trained individual must communicate and demonstrate to fully inform the new user of all protocols and hazards associated with this system.

1. Verify that the new user has attended the 3 hour Principles of Laser Safety course provided by the Office of Risk Management (ORM) at the University of Ottawa. This requirement can be fulfilled by reviewing the permit for this system, seeing a copy of the certificate provided by ORM upon successful completion of the course, or in writing by the Laser Compliance Specialist that the training was completed.
2. Ensure that a new user registration form has been completed and sent to ORM.
3. Provide these SOPs to the user and indicate all areas where they can be accessed including written and electronic formats.
4. Communicate who is currently authorized to use the system, the lab designate if not the principal investigator on the permit, and who to contact in case of an emergency including where the contact information can be located.

This example I wrote for a lab in Word (nothing fancy). Send to me for verification and guidance.
Guidelines for Class 3B and 4 Laser Alignment

**Getting started**

- Post **Notice** signs during alignment where lasers are normally **Class 1 or enclosed**
- Alignments done by those who have received laser safety training
- Exclude unnecessary personnel during alignment
- Wear protective eyewear for existing wavelengths

![AVIS NOTICE](image)
Guidelines for Class 3B and 4 Laser Alignment

During alignment

• Use **physical beam block** to block high-power beam at their source if not needed
  – *electronic shutters are dangerous*

• Use *low-power visible lasers* to simulate high-power laser path or use lowest possible power setting

• Place beam blocks behind optics to terminate beams
  – might miss mirrors during alignment

• Locate and block stray reflections properly before proceeding to next optical component (beam blocks)
  – ex: blocks versus beam dumps for high-power beams
Class 3B/4 Warning Devices
(Illuminated)
ATTENTION CAUTION

Class 2M Laser In Use

Do not stare into beam or view directly with optical instruments

Laser Type (Wavelength) xx mW maximum

ROOM Contact: Nom / Name  Poste / Ext
AVERTISSEMENT
WARNING

 Classe 4
Région contrôlée laser
Rayonnement laser visible et invisible
Éviter toute exposition des yeux ou de la peau à un rayonnement direct ou diffusé
Lunettes de protection laser obligatoires

Access autorisé seulement
Frapper avant d'entrer

Class 4
Laser Controlled Area
Visible and invisible laser radiation
Avoid eye and skin exposure to direct or scattered radiation
Laser protective eyewear mandatory

Authorized Access Only
Knock before entering

Laser Type (CW/Pulsed)  OD > Integer @ XXX nm  xx mW

2014 Bilingual Version
Most Class 3B and 4 Lasers

ROOM  Contact: Nom / Name  Poste / Ext
Class 4
Laser Controlled Area
Visible and invisible laser radiation
Avoid eye and skin exposure to direct or scattered radiation
Laser protective eyewear mandatory

Authorized Access Only
Knock before entering

Laser (CW/Pulsed): OD > Integer @ XXX nm
X J or W (Rep Rate)

2014 Bilingual Version

Highest hazard lasers (kW or non-traditional alignments)
Usually laser alignments
(changed conditions behind door)

Alignement du faisceau laser en cours
Changement à la classification des lasers et au niveau de risque

Laser Alignment in Process
Laser classification and hazard conditions changed

Entrée interdite
Do Not Enter

Laser En Effet / In Use:

Laser Type (CW/Pulsed)  OD > N @ xxx nm  xx W (xx Hz)

ROOM  Contact:  Nom / Name  Poste / Ext
International Laser Warning
Labels on Devices

Symbol and Border: Black
Background: Yellow
Placement: Output aperture

Legend and Border: Black
Background: Yellow
CAUTION: Class II, some IIIa
DANGER: Class IIIb and IV

INVISIBLE LASER RADIATION
AVOID EYE OR SKIN EXPOSURE
TO DIRECT OR SCATTERED RADIATION
CLASS 4 LASER PRODUCT

WAVELENGTH 10,600 nm
MAX LASER POWER 200 W
EN60825-1 1998
uOttawa Class 3B/4 Entryway

Highest Hazard

AVERTISSEMENT
WARNING

Classe 4
Région contrôlée laser
Rayonnement laser visible et invisible
Éviter toute exposition des yeux ou de la peau à un rayonnement direct ou diffusé
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Authorized Access Only
Knock before entering

Laser Type (CW/Pulsed)  OD > Integer @ XXX nm  xx mW

Room  Contact: Nom / Name  Phone: Poste / Ext

DANGER
LASER ACTIF
LASER ON

En cas d’urgence 5411 In case of emergency

Office of Risk Management
Laser Compliance Specialist ext.2000
PRIORITY #3
Personal Protective Equipment

CONTROL OF LASER HAZARDS
Laser Safety Eyewear

H. Eye and Face Protection

Mary never did like to wear safety goggles.
Peer pressure in the laser lab
Example: Laser Safety Eyewear Failure

An inexperienced graduate student lost 50% of his vision after sighting the reflecting beam of a Nd:YAG laser while wearing ordinary safety goggles as eye protection.

A more experienced student gave him the goggles
Laser Safety Eyewear: Which One?

- Determine laser wavelengths in use
- Choose OD to remain below exposure limit at each $\lambda$
- Avoid unnecessarily large ODs
  - Look at VLT (visible light tx)
- Comfort
- Prescription eyewear
Optical Density of Laser Safety Eyewear

Worst situation?
When the largest beam enters the eye, because it produces the smallest spot on the retina.

Area used in calculation: area of limiting aperture, provides a worst case OD based on the assumption that the entire beam enters the eye.

\[
\text{OD} = \log_{10} \frac{E}{\text{MPE}:E}
\]

(Eq. 4)

<table>
<thead>
<tr>
<th>OD</th>
<th>% Transmission</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>100%</td>
</tr>
<tr>
<td>1</td>
<td>10%</td>
</tr>
<tr>
<td>2</td>
<td>1%</td>
</tr>
<tr>
<td>3</td>
<td>0.1%</td>
</tr>
<tr>
<td>4</td>
<td>0.01%</td>
</tr>
<tr>
<td>5</td>
<td>0.001%</td>
</tr>
<tr>
<td>6</td>
<td>0.0001%</td>
</tr>
</tbody>
</table>
Laser Safety Eyewear: Labels

- All eyewear must be labeled with wavelength and optical density.

Without visible OD information, the goggles should **NOT** be used.
Laser Eyewear Analysis

- **Basics**: Assume MPE given \((W/\text{cm}^2\text{ or } \text{J/cm}^2)\)
- **Given**: Laser power \((\Phi)\) in Watts \((W)\)
  - or laser pulse energy \((Q)\) in Joules \((\text{J})\)
- Beams are usually smaller than dark-adapted eye
  - dark-adapted eye diameter is worst-case (tighter focus)
  - MPE referenced to lens-input
Laser Eyewear Analysis

\[ E = \frac{\Phi}{\pi w^2} \text{ W/cm}^2 \quad \text{or} \quad H = \frac{Q}{\pi w^2} \text{ J/cm}^2 \quad \text{Eq. 2, slide 15} \]

- \( w \) is usually dark-adapted pupil radius (0.35 cm)
  - when beam smaller than pupil
  - Area \( (\pi w^2) \) is 0.385 cm\(^2\)

\[ \text{OD} = \log_{10} \frac{E}{\text{MPE}:E} \quad \text{or} \quad \text{OD} = \log_{10} \frac{H}{\text{MPE}:H} \quad \text{Eq. 4, slide 100} \]

- CW exposure time is usually blink rate
  - \( \frac{1}{4} \) s visible, 10 s infrared, 100 s UV
- Pulsed laser is usually pulse width
# Laser Eyewear Analysis

## Continuous-Wave (CW)

*use Watt*

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Power</th>
<th>Duration</th>
<th>OD Formula</th>
<th>OD Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>405 nm</td>
<td>80 mW</td>
<td>¼ second</td>
<td>( \log_{10} \frac{208 \text{ mW/cm}^2}{2.54 \text{ mW/cm}^2} )</td>
<td>1.91 (2+)</td>
</tr>
<tr>
<td>800 nm</td>
<td>400 mW</td>
<td>10 seconds</td>
<td>( \log_{10} \frac{1.04 \text{ mJ/cm}^2}{100 \text{ nJ/cm}^2} )</td>
<td>4.02 (5+)</td>
</tr>
</tbody>
</table>

## Pulsed

*use Joule*

<table>
<thead>
<tr>
<th>Wavelength</th>
<th>Power</th>
<th>Duration</th>
<th>OD Formula</th>
<th>OD Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>800 nm</td>
<td>invisible &amp; IR; 400 mW</td>
<td>10 seconds</td>
<td>( \log_{10} \frac{1.04 \text{ mJ/cm}^2}{100 \text{ nJ/cm}^2} )</td>
<td>4.02 (5+)</td>
</tr>
<tr>
<td>100 fs</td>
<td>1 mm</td>
<td>less than 7 mm</td>
<td>( \log_{10} \frac{0.01 \text{ mJ/cm}^2}{100 \text{ nJ/cm}^2} )</td>
<td>1.91 (2+)</td>
</tr>
</tbody>
</table>
# Laser Safety Eyewear Quick Reference

## (400 – 1400 nm)

<table>
<thead>
<tr>
<th>Q-switched (1 ns – 10 ms)</th>
<th>Non Q-switched (0.4 ms – 10 ms)</th>
<th>CW (1/4 – 10 s)</th>
<th>OD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Max Output Energy (mJ)</td>
<td>Max Output Energy (mJ)</td>
<td>Max Output Power (W)</td>
<td></td>
</tr>
<tr>
<td>100</td>
<td>1000</td>
<td>1000</td>
<td>6</td>
</tr>
<tr>
<td>10</td>
<td>100</td>
<td>100</td>
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<td>10</td>
<td>10</td>
<td>4</td>
</tr>
<tr>
<td>0.1</td>
<td>1</td>
<td>1</td>
<td>3</td>
</tr>
<tr>
<td>0.01</td>
<td>0.1</td>
<td>0.1</td>
<td>2</td>
</tr>
<tr>
<td>0.001</td>
<td>0.01</td>
<td>0.01</td>
<td>1</td>
</tr>
</tbody>
</table>

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Office of Risk Management
Laser Compliance Specialist ext.2000
Laser Eyewear Analysis

<table>
<thead>
<tr>
<th>OD Specs</th>
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<tbody>
<tr>
<td>180 - 400 nm</td>
<td>6+</td>
</tr>
<tr>
<td>720 - 1090 nm</td>
<td>5+</td>
</tr>
<tr>
<td>750 - 1064 nm</td>
<td>7+</td>
</tr>
</tbody>
</table>

- Optical Density
- Wavelength (nm)

Office of Risk Management
Laser Compliance Specialist ext.2000
Nominal Hazard Zone

- The distance the laser must travel until its radiant exposure or irradiance drops below MPE

At laser output, it exceeds MPE

Laser eventually grows by its divergence angle (make sure you use full angle)

ex: $\theta = 0.1 \text{ mrad}$ grows linearly 0.1 mm in diameter for every 1 m of travel (good estimate for the far-field)
Nominal Hazard Zone

- The distance the laser must travel until its radiant exposure or irradiance drops below MPE

Start at 5 mm

When does $400 \, \mu J$ → $100 \, nJ/cm^2$

$\theta = 0.21 \, mrad$

$D = 4.8 \, km$

Not contained in a room
Reason for curtains & barriers

$d = 71 \, cm$
Non-Beam Hazards
Non-beam Hazards (NBH)

- Electrical
- Fire
- Chemical
- Laser-generated air contaminants (LGACs)
- Collateral and plasma radiation
- Explosion
- Noise
- Human Factors
- Fibre splicing
NBH: Electrical Hazards

- High voltage & current supplies
  - Experiments may use these sources too
  - Current limiting essential
- RF power supplies in some gas lasers
- Watch for improper grounding or shielding
- Failure to follow standard electrical safety procedures during maintenance and service:
  - Electrical shock
  - Burns
  - Blistering
  - Electrocution
NBH: Electrical Hazards

- Electrical equipment covered by Ontario Regulation 438/07

- Must have Certification or Field Evaluation marks
Example: Electrical Hazards

- Graduate student wiped condensate from CO₂ laser tube and received a 17 kV shock, suffered cardiac arrest and 2nd degree burns

- Repair technician fatally electrocuted working alone on CO₂ laser with interlocks defeated

- Serviceman electrocuted adjusting the power supply of copper vapour laser

- Senior scientist working alone electrocuted replacing high-voltage regulator in a laser power supply
Fire Hazards

- Class 4 Lasers:
  - Material beam enclosures
  - Barriers and stops
  - Wiring
  - potentially flammable if exposed to high beam irradiance for more than a few seconds

- Flammable solvents:
  - In enclosed area without adequate dilution or exhaust ventilation
  - pose fire or explosion hazard in presence of ignition source
Example: Fire Hazards

- Student used plain paper to check excimer beam accidentally place it in focal spot
  - Paper ignited
  - Triggered laboratory smoke alarm
  - No injury or fire occurred, but building was evacuated and fire crews arrived
Chemical Hazards

- **Laser Dyes (and solvents):**
  - toxic, carcinogenic, mutagenic, corrosive or flammable
  - Minimize exposure during solution preparation (see MSDS)

- **Far-IR optical materials** (windows and lenses) source of potentially hazardous levels of airborne contaminants:
  - CaTe, ZnTe burn in oxygen when beam irradiance exceeded

- **Cryogenic fluids** (liquid nitrogen, helium and hydrogen)
  - Skin and eye contact causes frostbite

- **Compressed gases**
  - Chlorine gas corrosive; He, Ar, N₂ asphyxiates; H is flammable
  - Unsecured cylinders
LGAC and Collateral Radiation

- Laser Ablation:
  - Materials may be carcinogenic or be harmful (tissue, ionic compounds like arsenic)
  - Sparks create plasma and X-rays
  - Plasma radiation emits UV

- High-intensity lasers can generate ozone when tightly focused
  - An irritant that can lead to chronic lung problems
LGAC and Collateral Radiation

- X-rays can be generated from high voltage (over 15 kV) power supply tubes
  - May cause tissue damage, leukemia or other cancers; permanent genetic effects
  
  www.uottawa.ca/services/ehss/x-ray-safety-prgm.html

- UV and visible radiation from laser discharge tubes and pumping lamps
  - The levels produced may exceed the MPE and cause skin and eye damage
  
  www.uottawa.ca/services/ehss/EMR.html
NBH: Explosion Hazards

• High pressure arc lamps or filament lamps can fail during operation
  – should be enclosed in a housing that withstands the maximum explosive force

• Targets and optics may shatter if heat cannot be dissipated quickly
  – Provide adequate mechanical shielding when exposing brittle materials to high intensity lasers
  – Vacuum windows can shatter
NBH: Noise

- Pumps for vacuum chambers can emit high frequency noises
  - Turbomolecular pumps can be very noising approaching end-of-life
  - Scroll pumps often best used in a separate room

- Excimer lasers emit a clacking sound with each pulse
NBH: Human Factors

- Lack of knowledge or understanding of equipment
- Lack of awareness of potentially hazardous conditions
- Underestimation of the risk
- Inappropriate attitude to safety – risk taking
- Conflict between safety and performance criteria
  - Poor safety leadership on the part of management
  - Poor communication on safety issues
- Lapses of attention and mistaken actions
Direct view of a laser experimental setup from computer area increases risk of eye exposure to direct or reflected beams.
NBH: Fibre Splicing

http://www.thefoa.org/tech/ref/safety/safe.html

• Shards invisible when next to water
• Shards can travel in bloodstream to heart
  – Cause secondary infections

• Goggles must be worn
• Waste must go in puncture-proof container
  – Tape the lid closed
• Use a black surface
10 Golden Rules of Laser Safety
Golden Rule #1

Wear laser safety eyewear

Ensure that you are using the appropriate one.

Remember laser radiation can be invisible, so just because you don't see anything does not mean that there is nothing!
Golden Rule #2

Do not look into the laser beam

Don’t look down specular reflections.

Don’t stare at diffuse reflections.
Golden Rule #3

Keep room lights on brightly, if possible

The brighter the ambient lighting, the smaller the eye's pupil will become and the chance of a laser beam entering the eye will be lessen.
Golden Rule #4

Remove personal jewellery

When entering a laser lab, remove anything which may pose a reflection hazard.

This is to protect you and your co-workers
Golden Rule #5

Locate and terminate all stray laser beams

Make sure that all stray beams are terminated with a matt, diffusing beam dump which is capable of handling the power of the laser beam
Golden Rule #6

Clamp all optical components securely

This helps your experiment from becoming misaligned and reduces the chances of a component moving and sweeping a laser beam over you.
Golden Rule #7

Keep beams horizontal

Horizontal beams are easier to work with and are predictable. Avoid vertical and skew beams if possible. Change beam height if necessary and be careful when aligning it.
Golden Rule #8

Don’t bend down below beam height

If you drop something, block the laser before picking up the object up.

If you can’t stop the beam, kick the object out of the way so you don’t trip over.
Golden Rule #9

Remember, optical components reflect, transmit and absorb light.

Often a transmitting component will also reflect light. This can lead to stray beams. Beware that optical components may change their characteristics when used with high power lasers.
Golden Rule #10

Don't forget non-optical hazards

Don't trip over, electrocute yourself, spill solvents, burn yourself on liquid nitrogen, ...
Laser Safety Program at uOttawa

• Contact me when **new lasers are purchased**
  – Preferably at grant writing stage
  – Discuss safety protocols
  – Help with hazard analysis

• Contact me when **new users arrive**
  – In-lab training documented
  – *Interim training performed*
  – *This course mandatory*

• Contact me with **any questions about lasers**
  – 14 years research experience in high-energy laser physics
  – Built and maintained many types of laser systems
Reporting Accidents

- Known or suspected eye injury should obtain IMMEDIATE medical attention. Time of treatment can often change the outcome and reduce long term effects.

- Call the emergency line 5411

- Call our office 5892 or the LSO at 2000

- Remember our websites
  www.uottawa.ca/services/ehss/index.htm
Before using Class 3B or 4 Lasers at uOttawa

• Make sure you know:
  – What are lasers hazards
  – How to identify lasers hazards in your work area
  – How to work safely with lasers
  – How to work safely around others

• Be Proactive not Reactive to laser hazards
Big Scary Laser
Do not look into beam with remaining eye

OMG LASERS!
PEW! PEW!
Before you leave...
Please remember

SAFETY IS NO ACCIDENT
References

# Recently Reported Laser News

<table>
<thead>
<tr>
<th>Date</th>
<th>Category</th>
<th>Link</th>
</tr>
</thead>
<tbody>
<tr>
<td>July 16, 2015</td>
<td>Airplane events - pilots with blurred vision</td>
<td>Good Morning America (Video)</td>
</tr>
<tr>
<td>Aug. 27, 2015</td>
<td>Non-Lethal Ocular Disruptor for crowd control</td>
<td>Yahoo News</td>
</tr>
<tr>
<td>Aug. 27, 2015</td>
<td>Compact Laser Weapons System (2 kW)</td>
<td>Boeing (Video)</td>
</tr>
<tr>
<td>Nov. 13, 2013</td>
<td>Spanish woman loses 60% vision from toy laser bought in China (0.5 to 6 W)</td>
<td>La Vanguardia (Original)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>La VanGuardia (Translated)</td>
</tr>
<tr>
<td>Mar. 28, 2014</td>
<td>FBI looking for suspects in laser incident with Delta</td>
<td>CBS</td>
</tr>
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