Laser Safety – Trends, Incidents, & Emerging Issues

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LLNL-PRES-XXXXXX

This work was performed under the auspices of the U.S. Department of Energy by Lawrence Livermore National Laboratory under contract DE-AC52-07NA27344. Lawrence Livermore National Security, LLC

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ANSI Hazard Class Review

Three major lasing mediums:

- Solid-State
  - Diodes
  - Fiber
  - OPSL lasers
- Liquid
- Gas

Four primary power classifications:

- Class 1 (Very low power, or enclosed)
- Class 2 (Only for Visible)
- Class 3R (Wavelength dependent, but <5mW)
- Class 3B (3R through <0.5W)
- Class 4 (Anything >0.5W)

*NOTE: Power levels dependent on wavelength, other factors

Laser Class	Approx. Power	Hazards
Class 1	Various	Safe under normal operating conditions
Class 2	Visible <1mW	Safe without magnifying optics
Class 3R	< 5mW	Can produce spot blindness, other eye injuries
Class 3B	< 0.5W	Can damage eyes, skin
Class 4	> 0.5W	Can damage eyes, skin, ignite fires

Incident Trends – US Dept. of Energy

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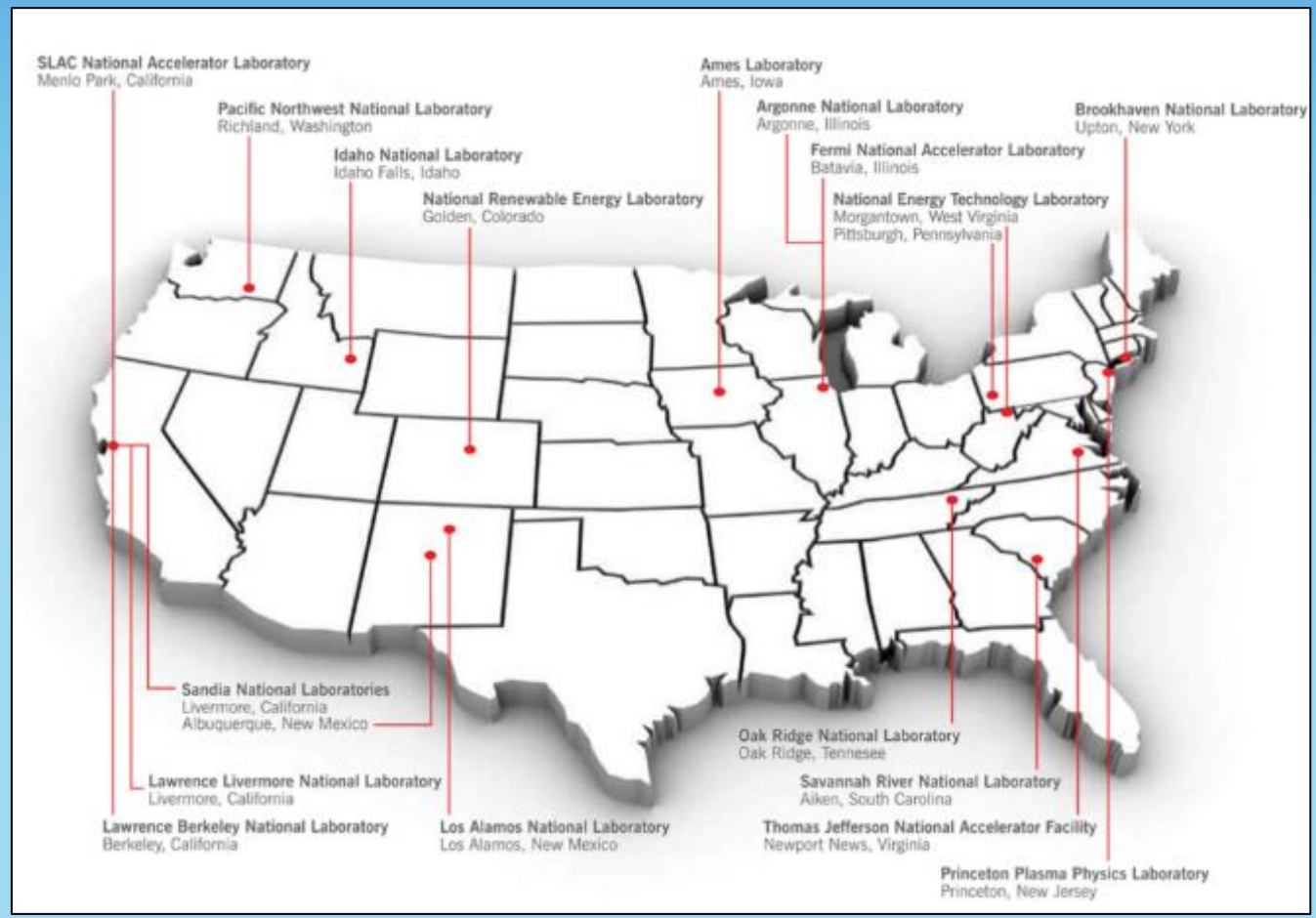
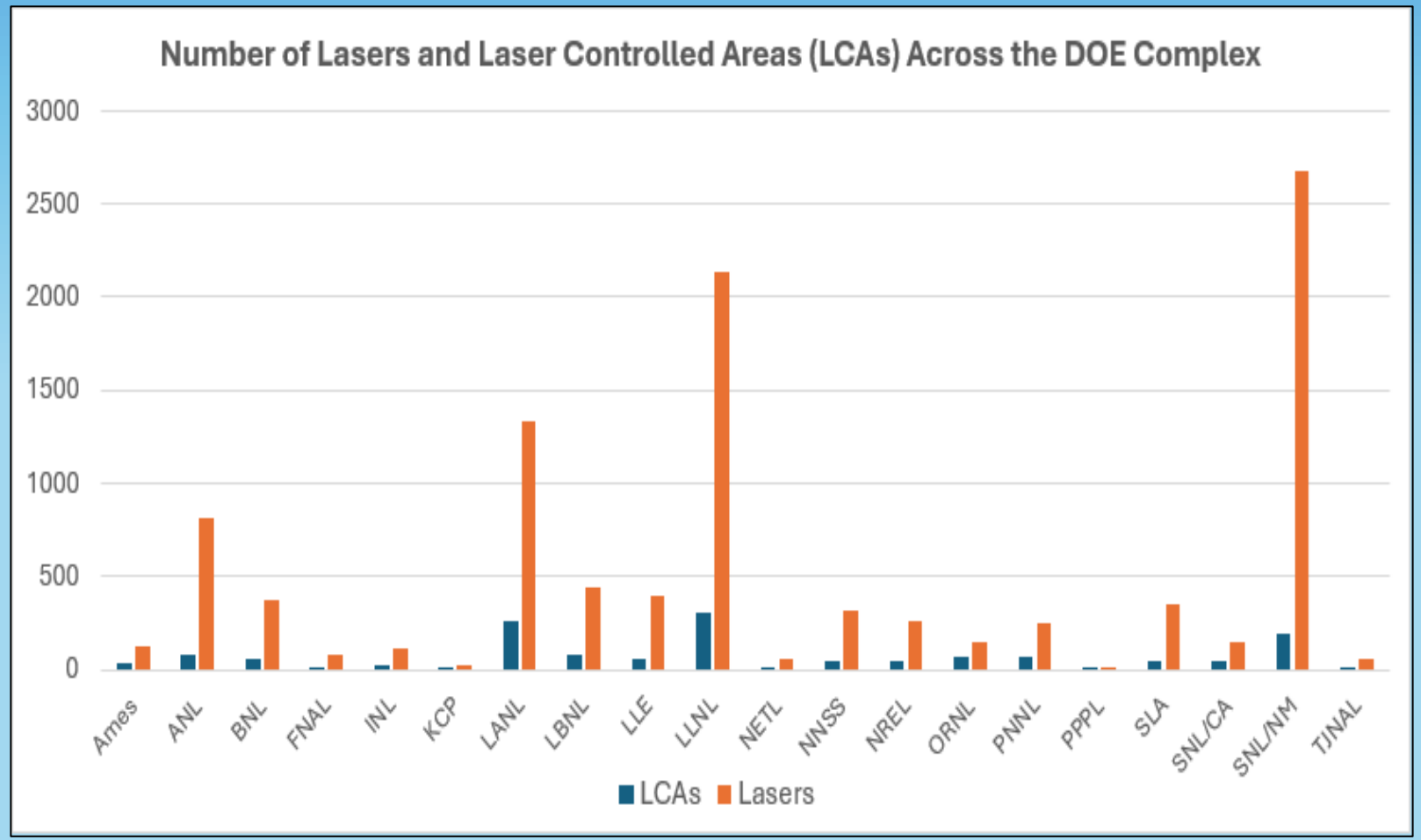
State of Laser Safety Across the DOE Complex

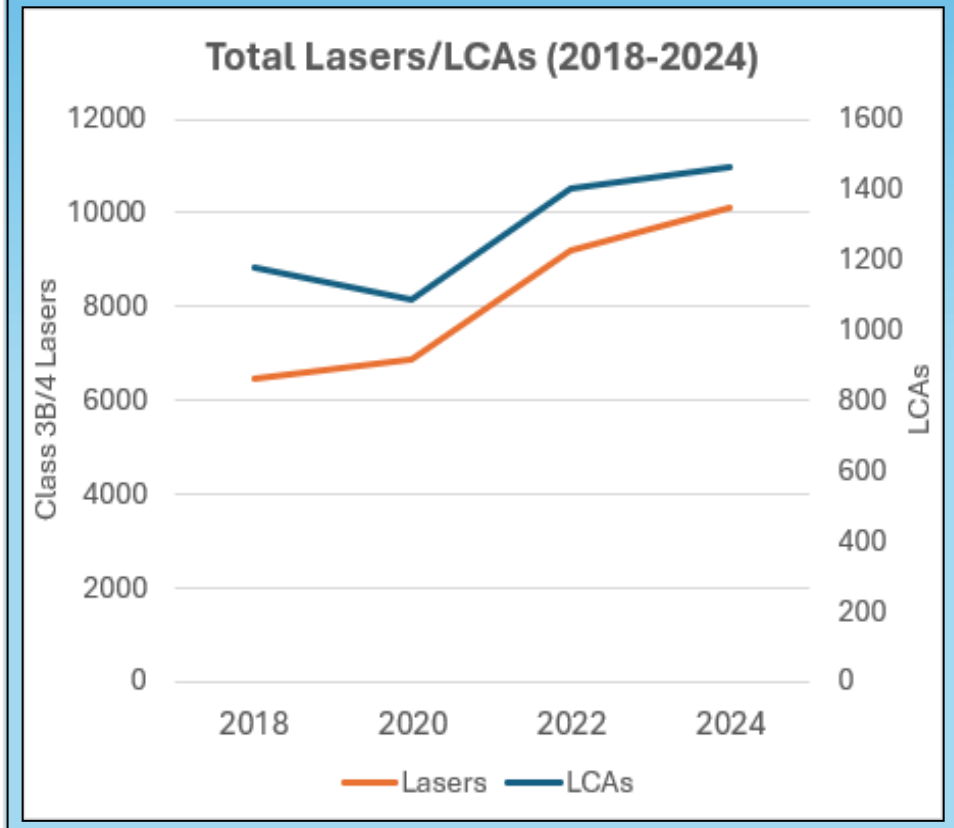
- Currently:
  - >1,500 Laser Controlled Areas
  - >10,000 High Powered (Class 3B/4) Lasers
  - Numbers increasing annually
- Good cohort to study!
- Lots of people, lasers, activity variation
- Majority of laser work is R&D
- Numerous near misses, off-normal events documented



Near misses result from inattention to details. Accidents result from neglecting lessons learned.

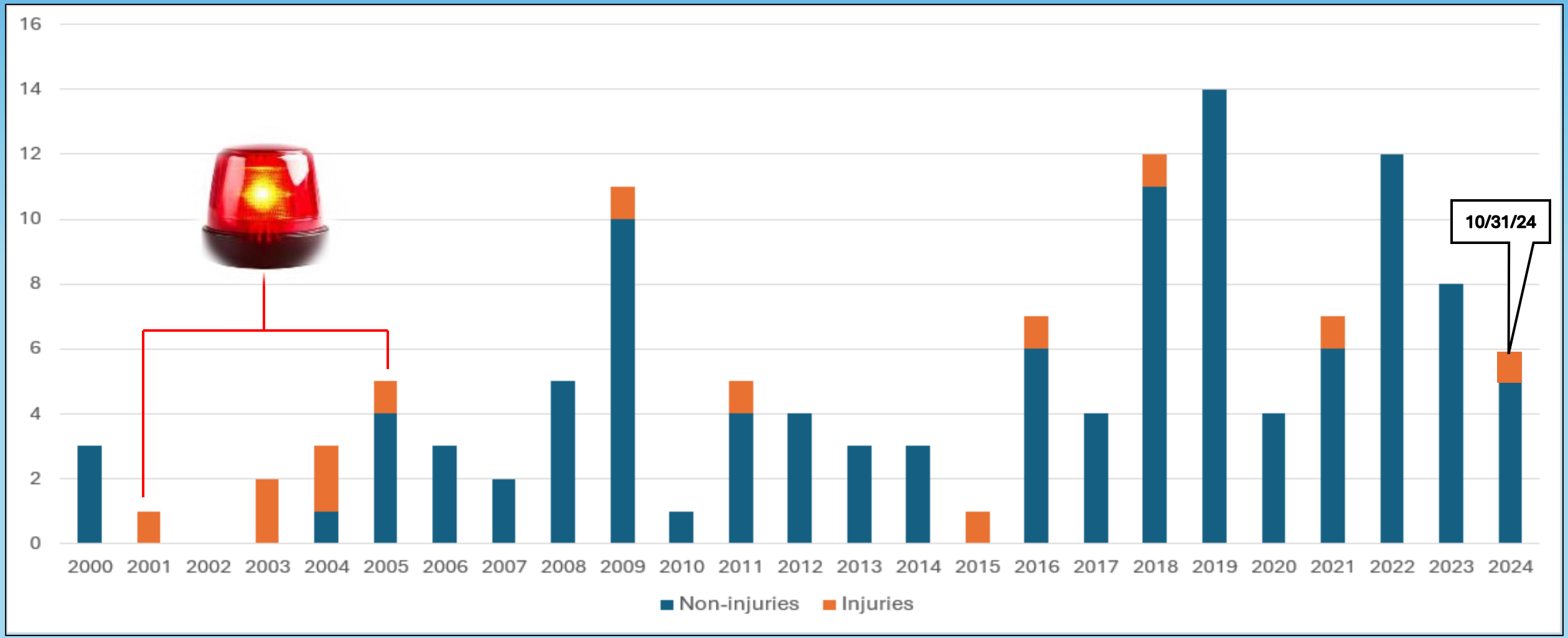
Laser Controlled Areas, Class 3B/4 Lasers Across DOE





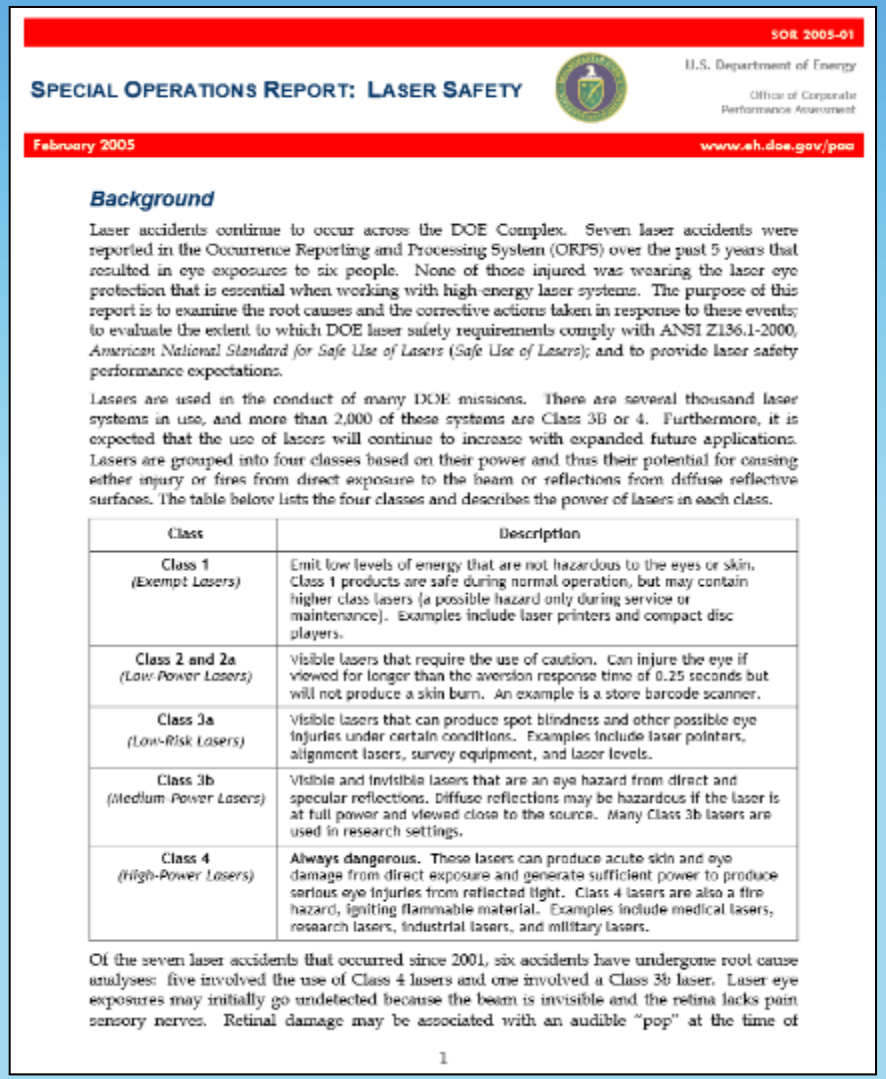
Laser use across the complex is accelerating, from low to very high power

DOE Laser-Related Off-Normal Events (2000-2024)



DOE Special Operations Report

- Issued in 2005
- 7 accidents (2001-2005)
- 6 individuals injured
- Eyewear was not worn in all cases
- Many students involved
- Some infamous within laser safety community
- Don't become the next case study!



SOR 2005-01

U.S. Department of Energy

Office of Corporate Performance Assessment

SPECIAL OPERATIONS REPORT: LASER SAFETY

February 2005

www.eh.doe.gov/paa

Background

Laser accidents continue to occur across the DOE Complex. Seven laser accidents were reported in the Occurrence Reporting and Processing System (ORPS) over the past 5 years that resulted in eye exposures to six people. None of those injured was wearing the laser eye protection that is essential when working with high-energy laser systems. The purpose of this report is to examine the root causes and the corrective actions taken in response to these events; to evaluate the extent to which DOE laser safety requirements comply with ANSI Z136.1-2000, *American National Standard for Safe Use of Lasers* (*Safe Use of Lasers*); and to provide laser safety performance expectations.

Lasers are used in the conduct of many DOE missions. There are several thousand laser systems in use, and more than 2,000 of these systems are Class 3B or 4. Furthermore, it is expected that the use of lasers will continue to increase with expanded future applications. Lasers are grouped into four classes based on their power and thus their potential for causing either injury or fires from direct exposure to the beam or reflections from diffuse reflective surfaces. The table below lists the four classes and describes the power of lasers in each class.

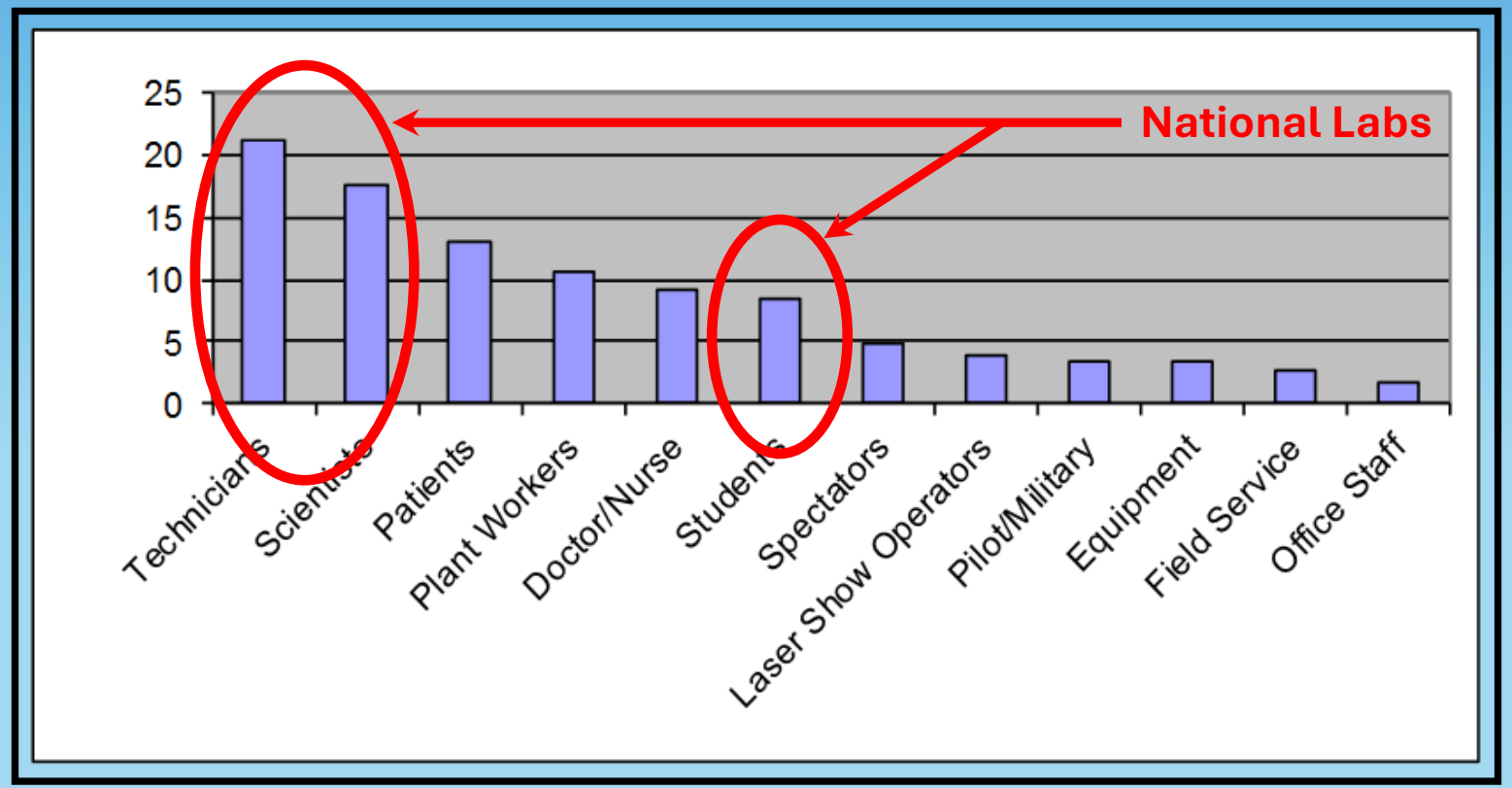
Class	Description
Class 1 *(Exempt Lasers)*	Emit low levels of energy that are not hazardous to the eyes or skin. Class 1 products are safe during normal operation, but may contain higher class lasers (a possible hazard only during service or maintenance). Examples include laser printers and compact disc players.
Class 2 and 2a *(Low-Power Lasers)*	Visible lasers that require the use of caution. Can injure the eye if viewed for longer than the aversion response time of 0.25 seconds but will not produce a skin burn. An example is a store barcode scanner.
Class 3a *(Low-Risk Lasers)*	Visible lasers that can produce spot blindness and other possible eye injuries under certain conditions. Examples include laser pointers, alignment lasers, survey equipment, and laser levels.
Class 3b *(Medium-Power Lasers)*	Visible and invisible lasers that are an eye hazard from direct and specular reflections. Diffuse reflections may be hazardous if the laser is at full power and viewed close to the source. Many Class 3b lasers are used in research settings.
Class 4 *(High-Power Lasers)*	**Always dangerous.** These lasers can produce acute skin and eye damage from direct exposure and generate sufficient power to produce serious eye injuries from reflected light. Class 4 lasers are also a fire hazard, igniting flammable material. Examples include medical lasers, research lasers, industrial lasers, and military lasers.

Of the seven laser accidents that occurred since 2001, six accidents have undergone root cause analyses: five involved the use of Class 4 lasers and one involved a Class 3b laser. Laser eye exposures may initially go undetected because the beam is invisible and the retina lacks pain sensory nerves. Retinal damage may be associated with an audible "pop" at the time of

1

Some injuries were severe, permanent, and caused months-long suspension in operations

Which Roles Are Most Affected?



Technicians (21.3%), Scientists (17.6%), Students (8.4%)

Nearly 50% of accidents affect personnel found at National Labs

Incident Case Studies, Lessons Learned

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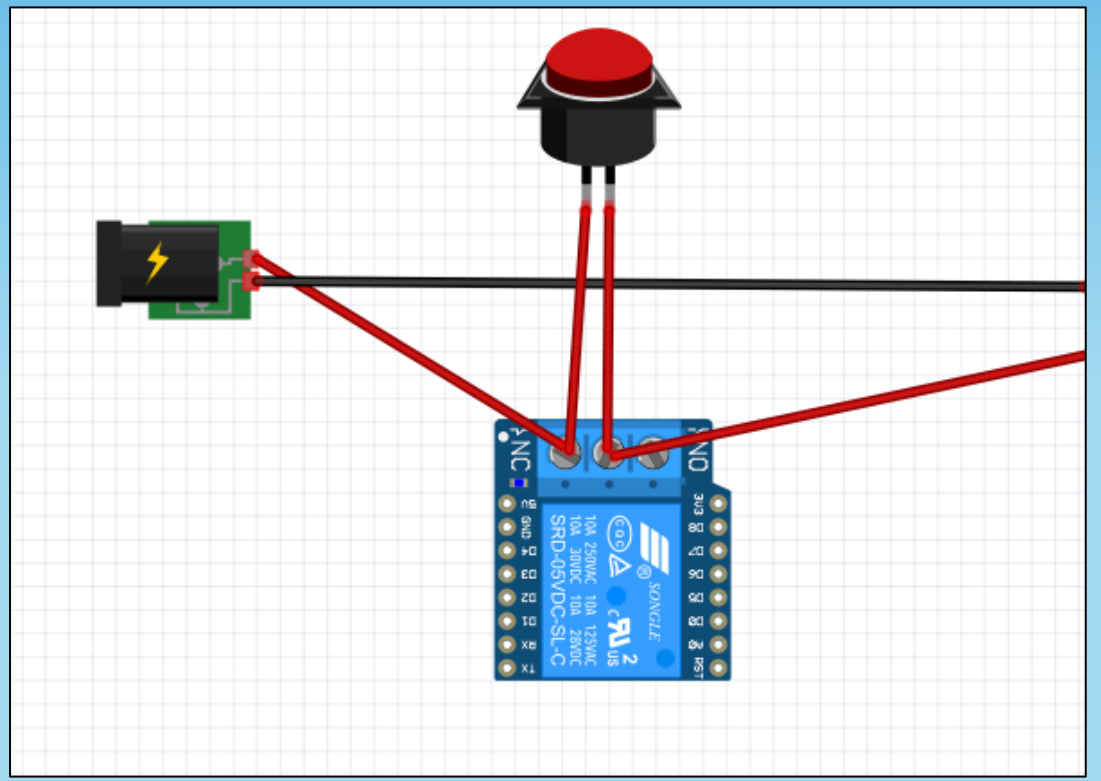
Idaho National Laboratory

- Worker 1 using system to cut acrylic, left area
- Worker 2 identified fire, extinguished
- Air Assist system to keep combustible gasses away from cutting surface
- Turned off for 2 years
- Manufacturer recommended NOT operating unattended when cutting acrylics

Always follow manufacturer instructions, such systems are NOT equal to plug & play laser printers

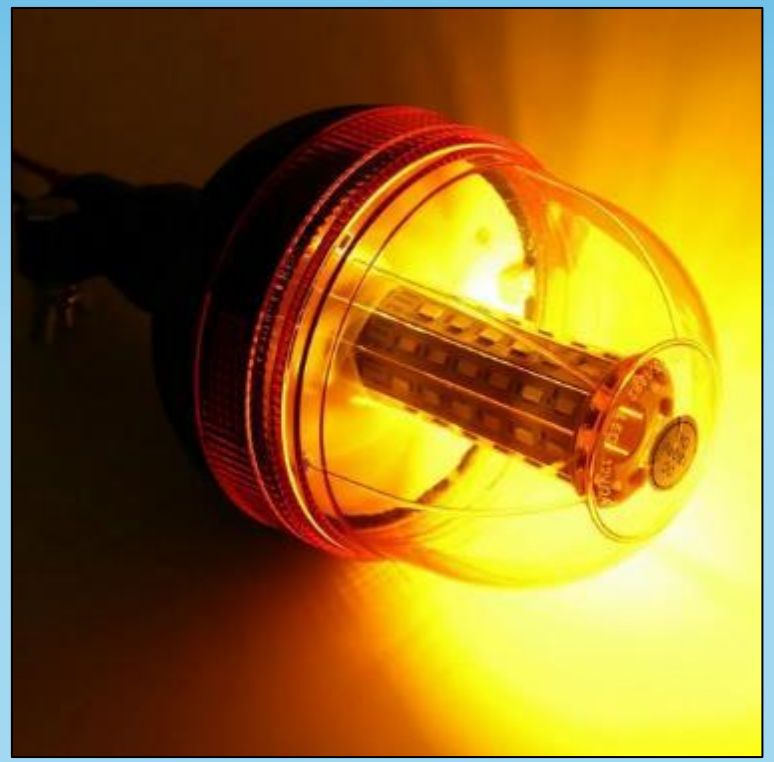
Los Alamos National Laboratory

- Two workers potentially exposed from a Class 1 enclosed engraver
- Workers unintentionally overrode interlock
- System found operating with enclosure open
- No longer a Class 1 system!
- Mfg. installed a hidden bypass
- Hold button for 3 seconds, interlock turns off
- Mfg. “surprised anyone discovered” override
- Bypass was removed



Be Aware of all “Bypass” Functions on Class 1 Laser Systems!

Lawrence Livermore National Laboratory



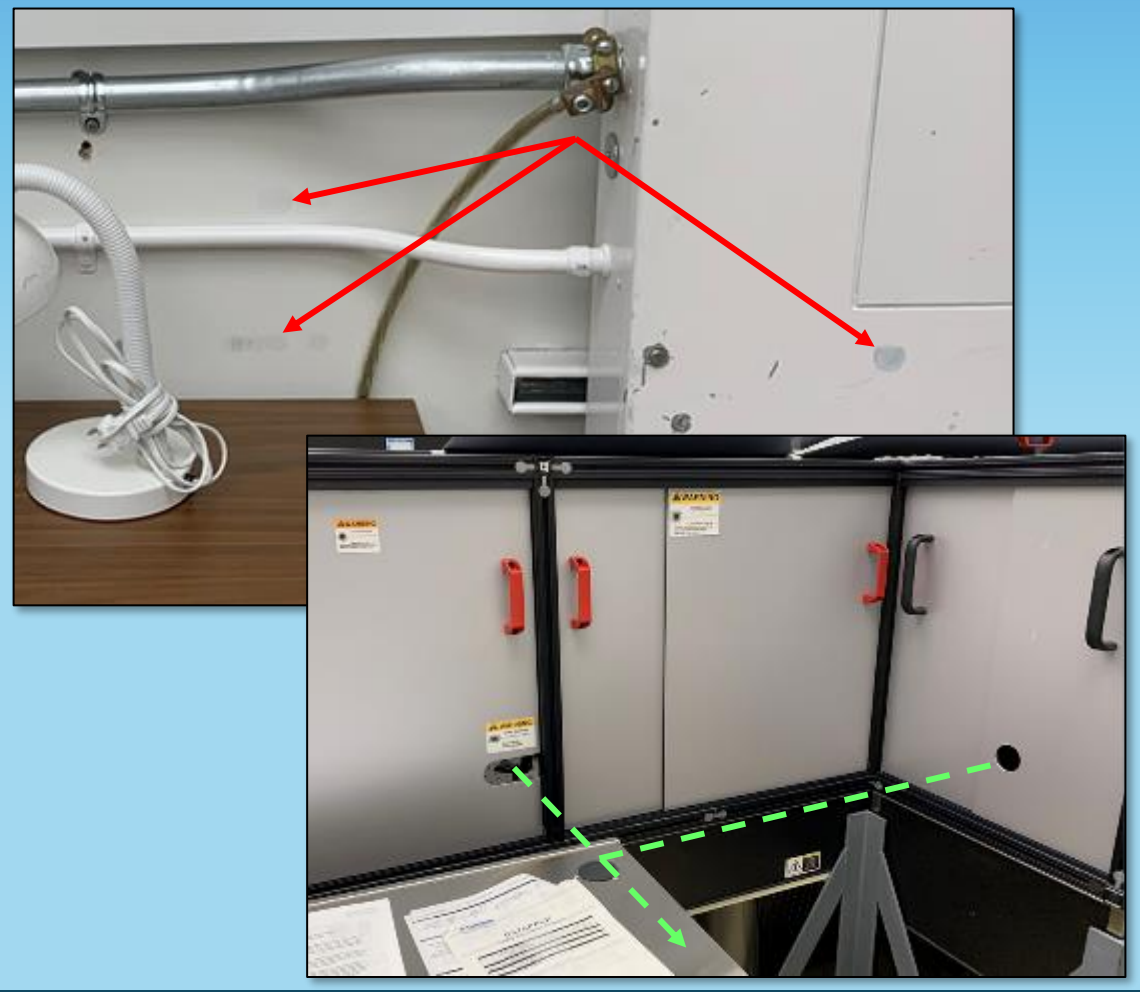
- Worker 1 using laser with special eyewear
- Eyewear limited to two pairs
- Worker 1 swept room, donned eyewear, operation commenced
- Worker 2 in another part of room left, saw warning beacon
- Worker 2 realized they were missed during the sweep, reported
- Worker 2 was wearing headphones, did not hear call-out
- Worker 1 didn't search area behind partition where Worker 2 was

Administrative Controls + Human Performance = Failure (at some point)

Lawrence Livermore – Fiber Dust Caps

- A fiber carrying 2W left on during troubleshooting
- System approved for Class 1 enclosed operation
- Fiber end covered by plastic dust cap, directed downward
- Operator soon noticed laser burnt through cap
- Work was not paused or stopped, not reported until several weeks later, not seen as problem
- Scope Creep – Breaking configuration warrants LSO input
- Dust caps are not beam dumps

Burns on Secondary Barriers



- During audit, LSO discovered burn marks on wall
- Investigation found cause was turning mirrors and removed barriers
- Beam block not installed at the output
- Loss of beam control is reportable incident
- User did not feel it was “that big of a deal”

Report off-normal events. Lessons learned may help others. “Help us help you!”

High Power Laser Lab

- Audit of an off-site facility was requested
- Eyewear showed laser induced damage
- Several layers of safety controls missed or violated
- Eyewear exposure must be investigated
- Remove from service!
- “Respirator analogy,” doesn’t fly
- Safety culture in need of overhaul

Lawrence Berkeley National Laboratory

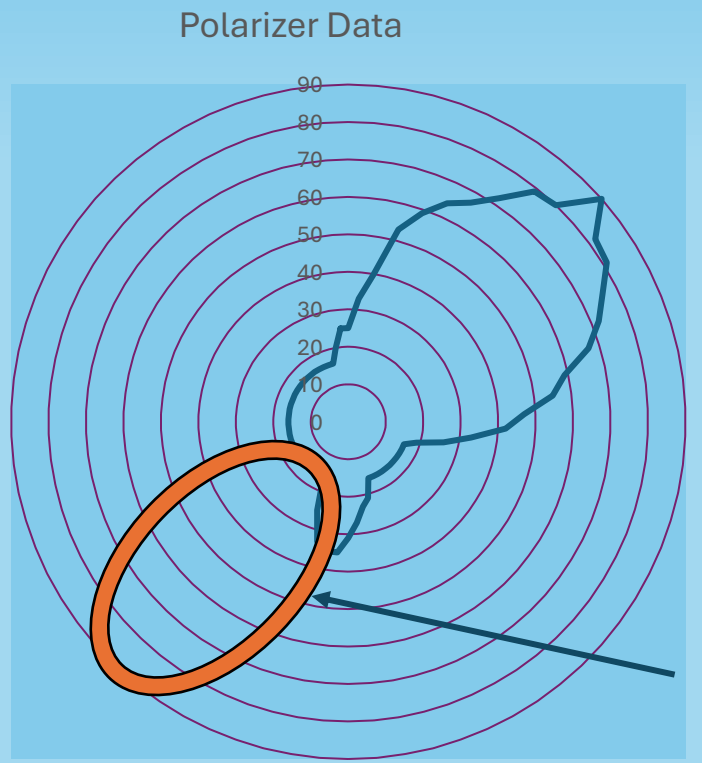
- Leveling construction laser shining in office window
- Laser left on and unattended over break
- Beam shined twice in eye of the person in office
- Happened a week later with beam hitting interior wall
- Work paused by the LSO
- No Injury reported, but significant oversight
- Not every user receives same safety training

Even low power lasers can cause alarm and disruption

Beam Splitting Polarizer & Human Factors

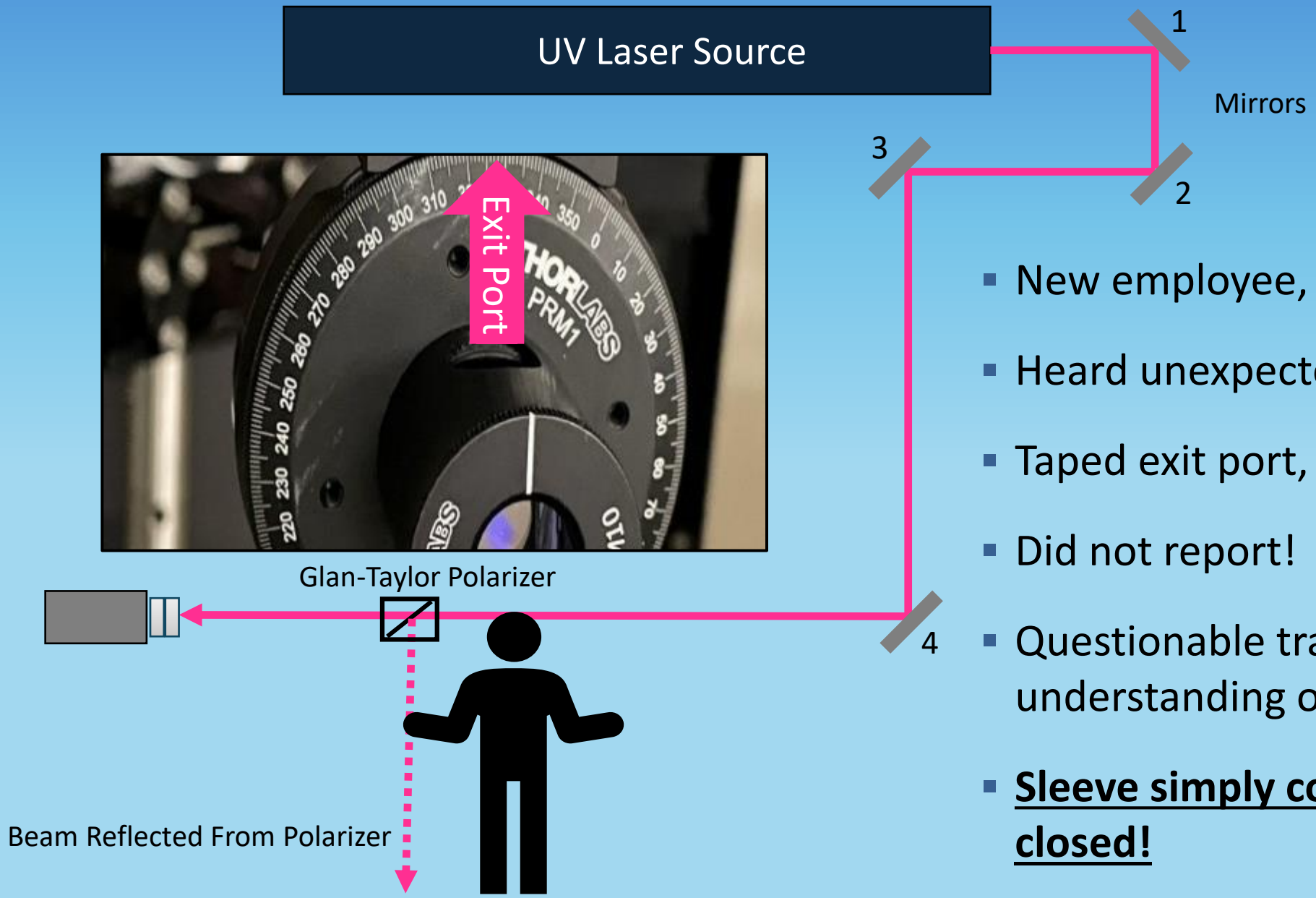
Goal: Test for abnormalities, fringes, ghost reflections, multiple beams.
Determine if power profile of input, output equal.

Glan-Taylor Polarizer



Expected Pattern
Not Observed

Same problematic optic led to 10/31/24 eye exposure! Now a focus in Alignment Training



- New employee, working along
- Heard unexpected “clicking”
- Taped exit port, continued
- Did not report!
- Questionable training sufficiency, understanding of optics
- **<u>Sleeve simply could have been closed!</u>**

What sorts of Human Factors are at play here?

Human Factors

- Incomplete knowledge of component
- Insufficient communication between staff
- Different recollections of training, proficiency
- Working alone
- No indication of exposure, stray beam
- Inadequate incident response
- With late reporting, memories and scene change
- Don’t want to look bad, risk discipline
- Beam splitting polarizers are common contributors to incidents, injuries

Laser Safety and Industrial Hygiene Overlap

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Teamwork for Non-Beam Hazards

- Fire, ignition hazards
- LGAC – Laser Generated Air Contaminants
- Plasma production
- Non-laser radiation – RF, EMF, microwave, ionizing
- Electrical, arc-flash
- Compressed gasses, pressurized lamps, refrigerants
- Fiber optic hazards (breaks, punctures)
- Misc. chemical agents

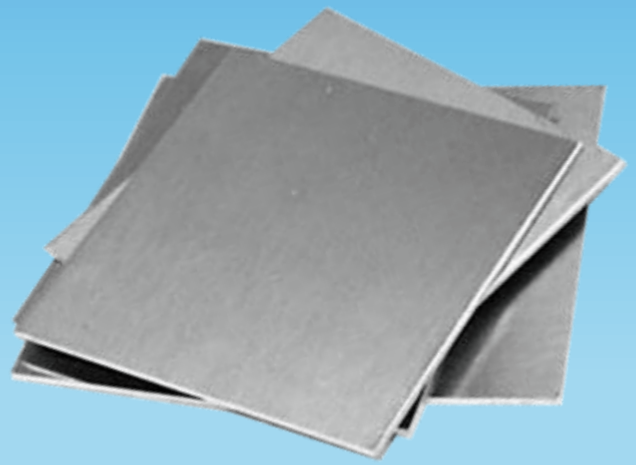
Air Contaminants

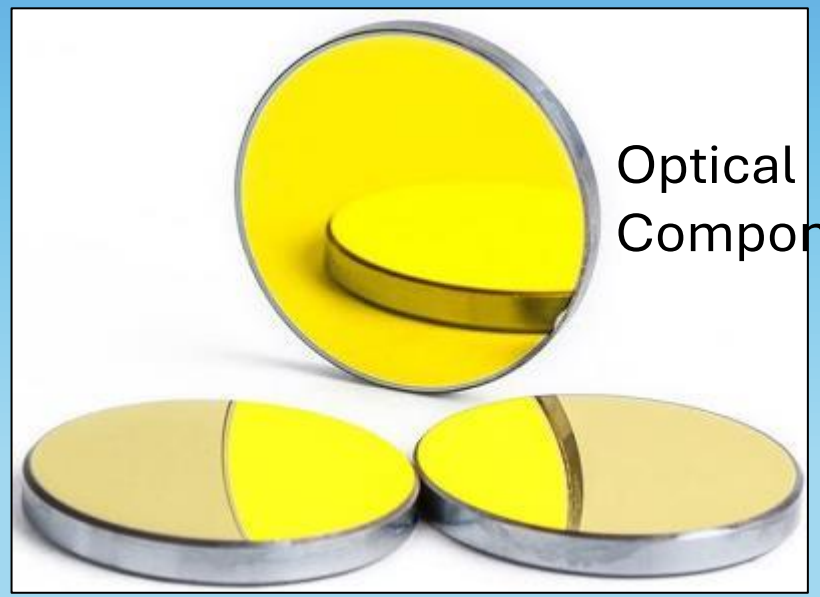
7.3.1 Laser generated Air Contaminants (LGAC). Air contaminants may be generated when certain Class 3B and Class 4 laser beams interact with matter. The quantity, composition, and chemical complexity of the LGAC depend greatly upon target material, cover gas, and the beam irradiance. The LSO shall ensure that industrial hygiene aspects of exposure to LGAC are addressed and that appropriate control measures are effected.

Excerpt from ANSI Z136.1 American National Standard for Safe Use of Lasers

Common Materials in Laser Labs

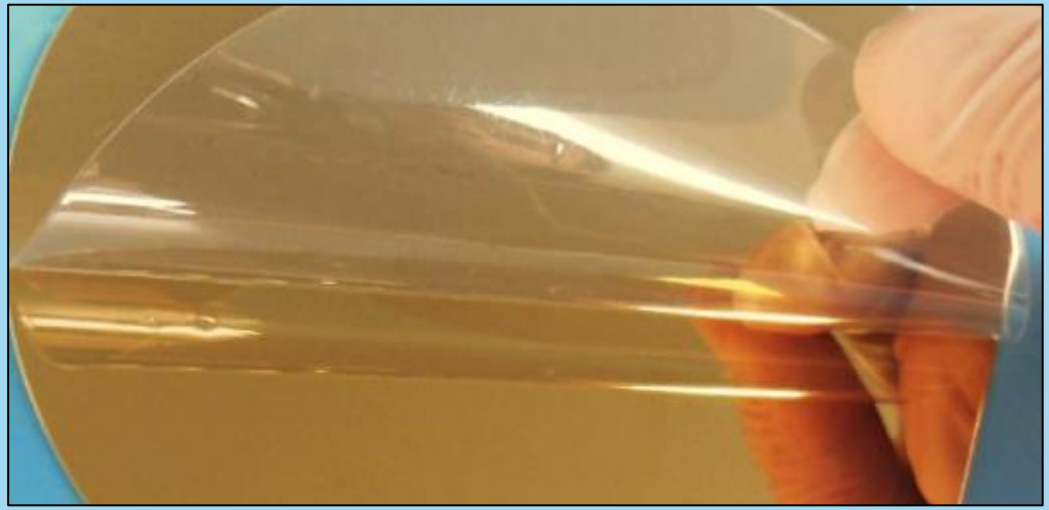
Stainless Steel

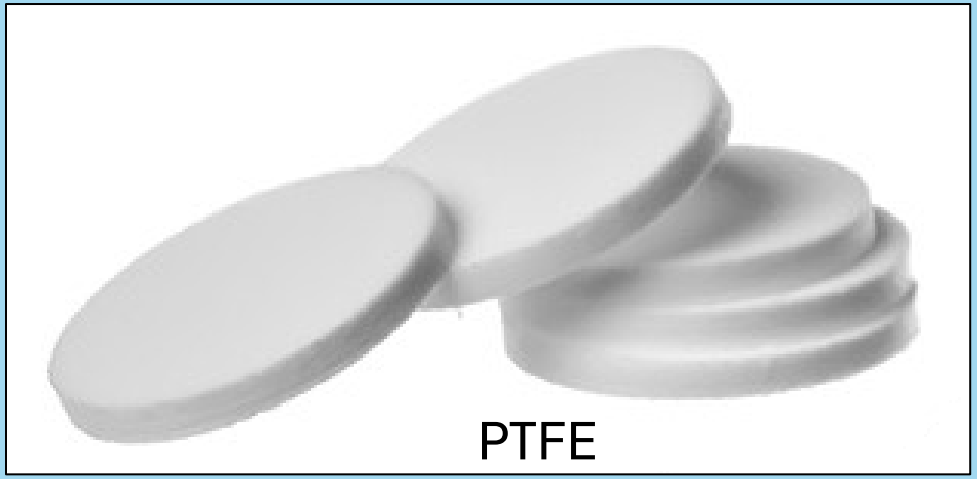




Optical Components

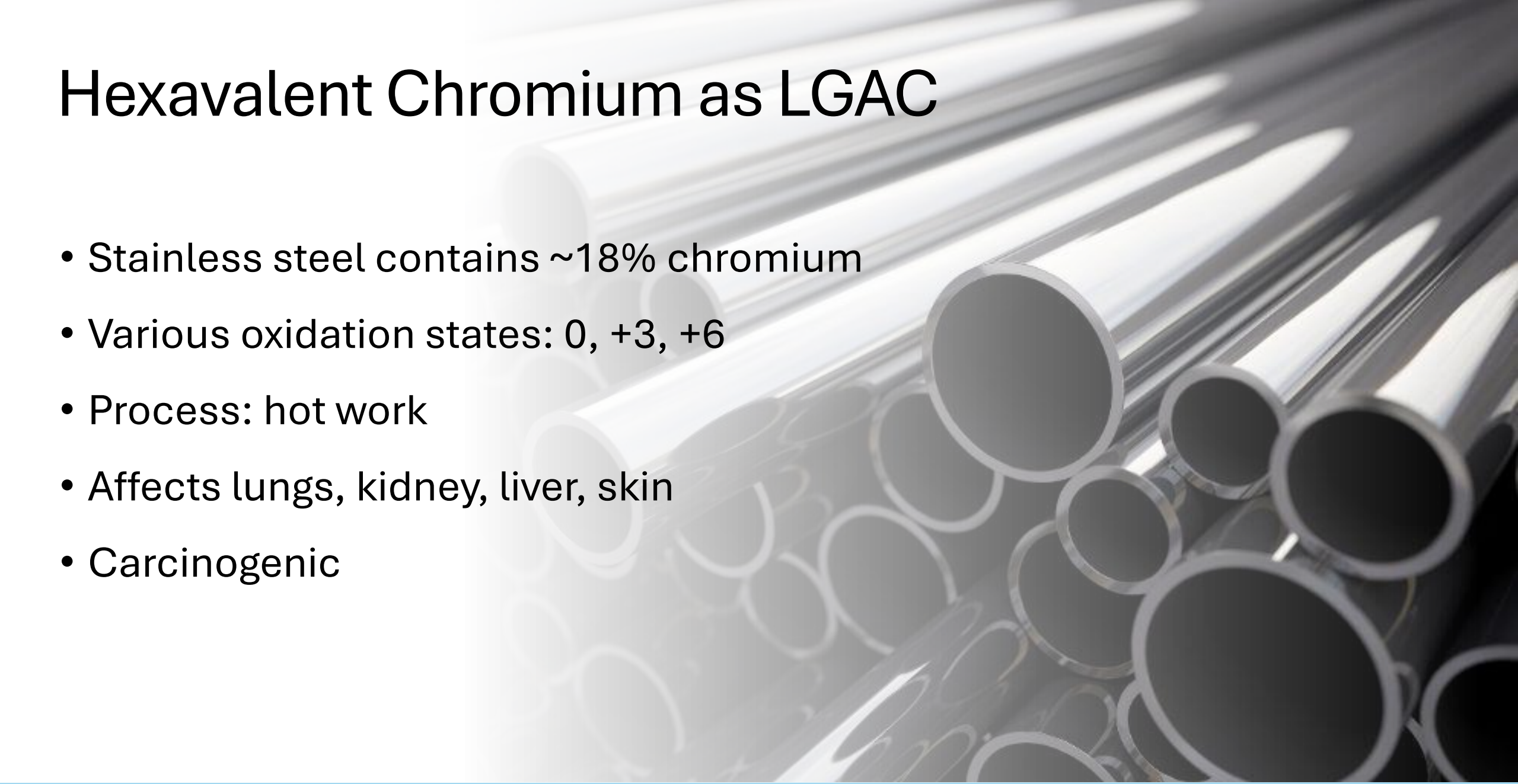
Parylene





PTFE

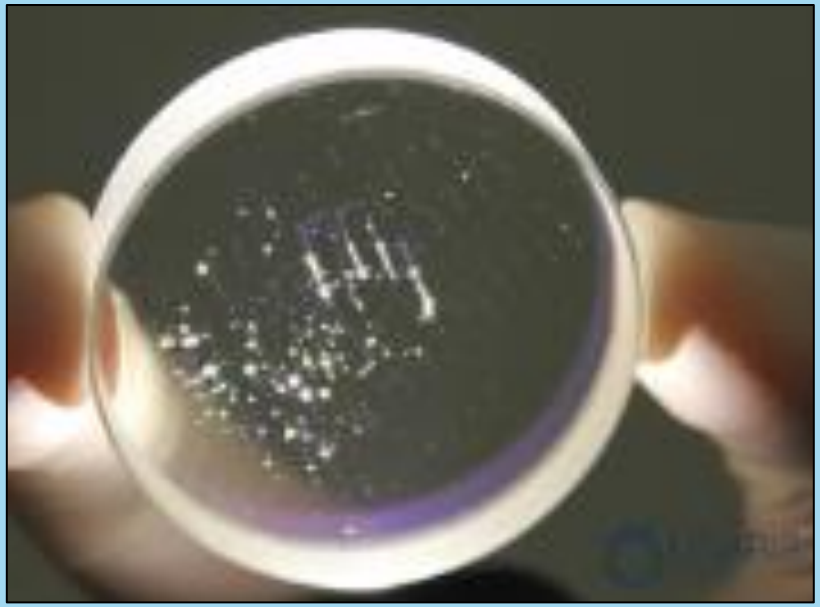
Hexavalent Chromium as LGAC



- Stainless steel contains ~18% chromium
- Various oxidation states: 0, +3, +6
- Process: hot work
- Affects lungs, kidney, liver, skin
- Carcinogenic

Crystalline Silica as LGAC

- Natural material
- Found in quartz, optics, glass
- Process: ablation
- Lung diseases, cancer
- Inspect optics, chamber windows!



Laser Cleaning Products – The New Hot Commodity

Hundreds to thousands of watts! Beam path, hazardous vapors, stray reflections.

LGACs Quantitative Assessment

- Laser spot size, irradiance
- Material thickness, density
- Volume of area/space
- Various applicable OELs
  - Regulatory (OSHA)
  - Professional committees (ACGIH)
  - TWA, Ceiling Limit, STEL

Emerging Issues in Laser Safety

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Counterfeit Lasers & FDA Certification

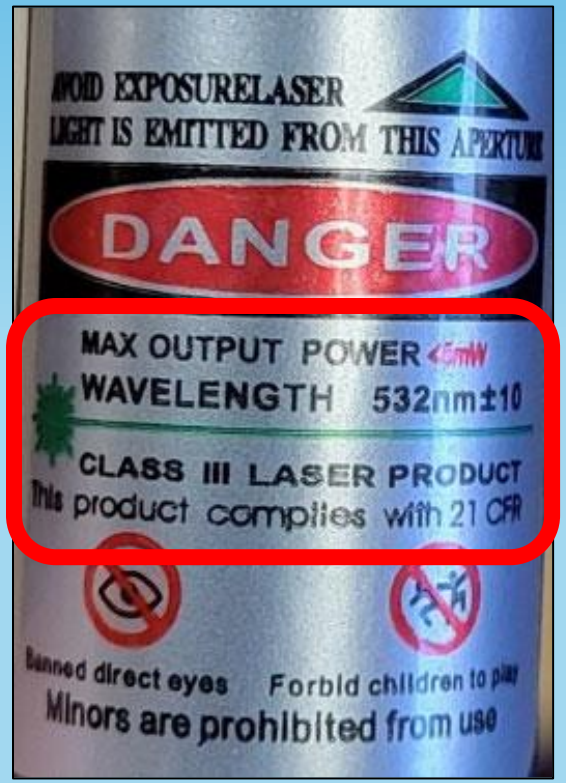
- Laser products self-certified by manufacturer before entering commerce
- Process is dependent on intent to follow law
- FDA grants accession number (notice of receipt)
- FDA cannot provide info to users upon reference
- How do we distinguish legitimate products that comply with standards from those that do not?
- What good is the accession number?
- FDA has not clarified

FDA U.S. FOOD & DRUG ADMINISTRATION
CENTER FOR DEVICES & RADIOLOGICAL HEALTH

LAWRENCE LIVERMORE NATIONAL LABORATORY
LASER SAFETY OFFICE

Laboratory for Laser Energetics

- Laser pointers ordered for conference gifts
- Recipient questioned output power
- LSO asked to verify
- Lasers marked as <5mW and “Class III” laser product
- FDA IIIa, or ANSI 3R is correct classification
- Lasers measured with greater than 30mW
- Delivered with diffractive optics on output for shapes, patterns
- Easily removed
- Units also found in LLNL Discovery Center, conference rooms

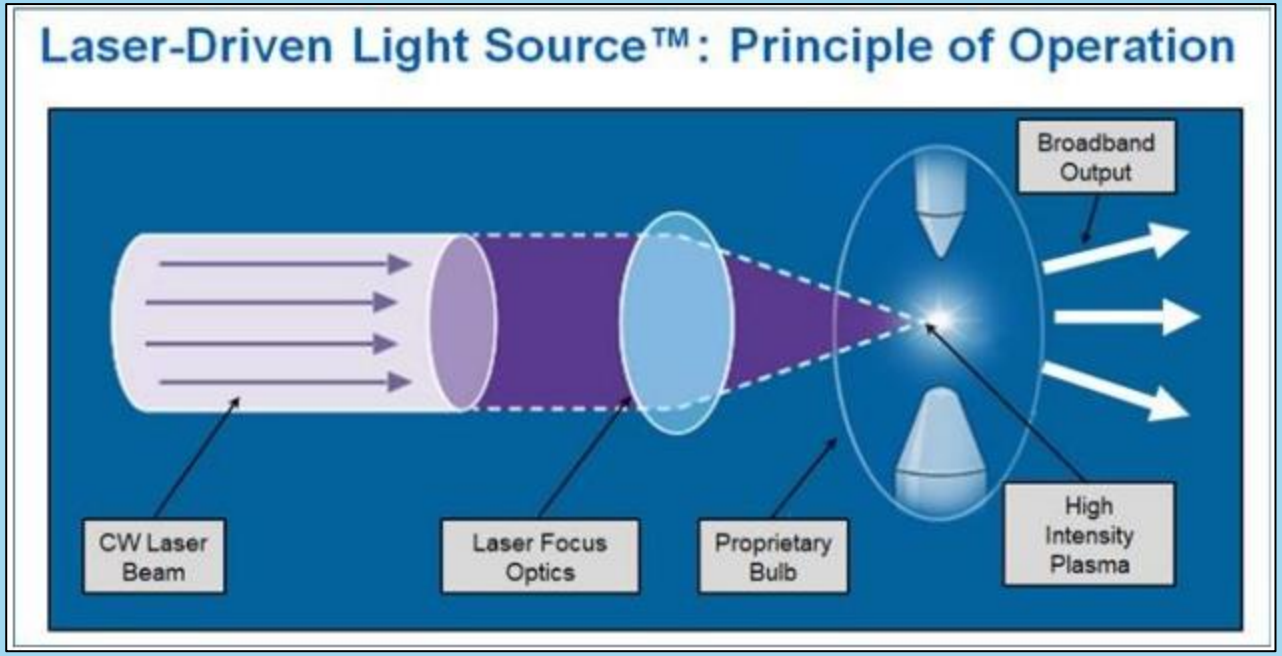


Class 3R compliant laser pointers are nearly impossible to find!

Incoherent Light Sources

- Light Emitting Diodes, Laser Driven Light Sources, Supercontinuum
- Very bright! No upper limit
- Laser light leakage?
- Significant performance, quality improvement
- No domestic regulations or standards
- IEC 62471 and IEC 60598
- IEC Risk Groups

Risk Group	Philosophical Basis
Exempt	No photobiological hazard
Group 1 (Low-Risk)	No photobiological hazard under normal behavioral limitations
Group 2 (Moderate-Risk)	Does not pose a hazard due to aversion response to bright light or thermal discomfort
Group 3 (High-Risk)	Hazardous even for momentary exposure



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- Class 4 (Anything >0.5W)
- Class 5 (Proposed, Non-ANSI)

*NOTE: Power levels dependent on wavelength, other factors

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Need for Class 5 Laser Safety

- Kilowatt CW to petawatt pulsed lasers widespread, growing
- Hazards exceed scope of ANSI Z136
- OSHA General Duty Clause – Address recognized hazards
- Lockheed Martin and DOE collaboration
- Class 5 lasers >10kW for CW
- 10^{15} W/cm^2 peak irradiance <0.25 seconds
- Weaponized lasers, designed to destroy, penetrate materials, IDLH, hazardous diffuse reflections
- Avoid burden on existing industry
- Consider burn-through rates of materials, infrastructure
- Thermal management, battery ops
- Multiple, redundant interlock systems
- Error prevention techniques, huddles
- Eyewear NOT considered

Development Process

1. White Paper arguing for ANSI updates, new hazard class
2. Assemble team of SMEs
3. Propose changes to ANSI Z136.1
4. Develop appendix, table with recommendations
5. Integrate into processes to set industry standard
6. Work with ANSI board to publish (longer term goal)

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LOCKHEED MARTIN

ANSI
American National Standards Institute

nsc
National Safety Council

Winner of National Safety Council 2022 Innovation Award

Class 5 Safety Controls

a) Personnel exclusion – Remote operation, breakdown of PPE

b) Beam shields, laser barriers – Construction materials considered

c) Beam blocks, dumps – Special design, may require thermal management

d) Containment of specular, diffuse reflections – Low power alignments, dry runs

e) Optical damage sensors – Stray light, smoke detection, temp monitoring

f) Entryway controls – Key controlled interlock, status indicators

g) Operational checklists – Error prevention, consistency

h) Detailed alignment procedures – Highest risk, 90% of incidents

i) Back reflections – Small percentage of reflected HEL beam can far exceed MPE

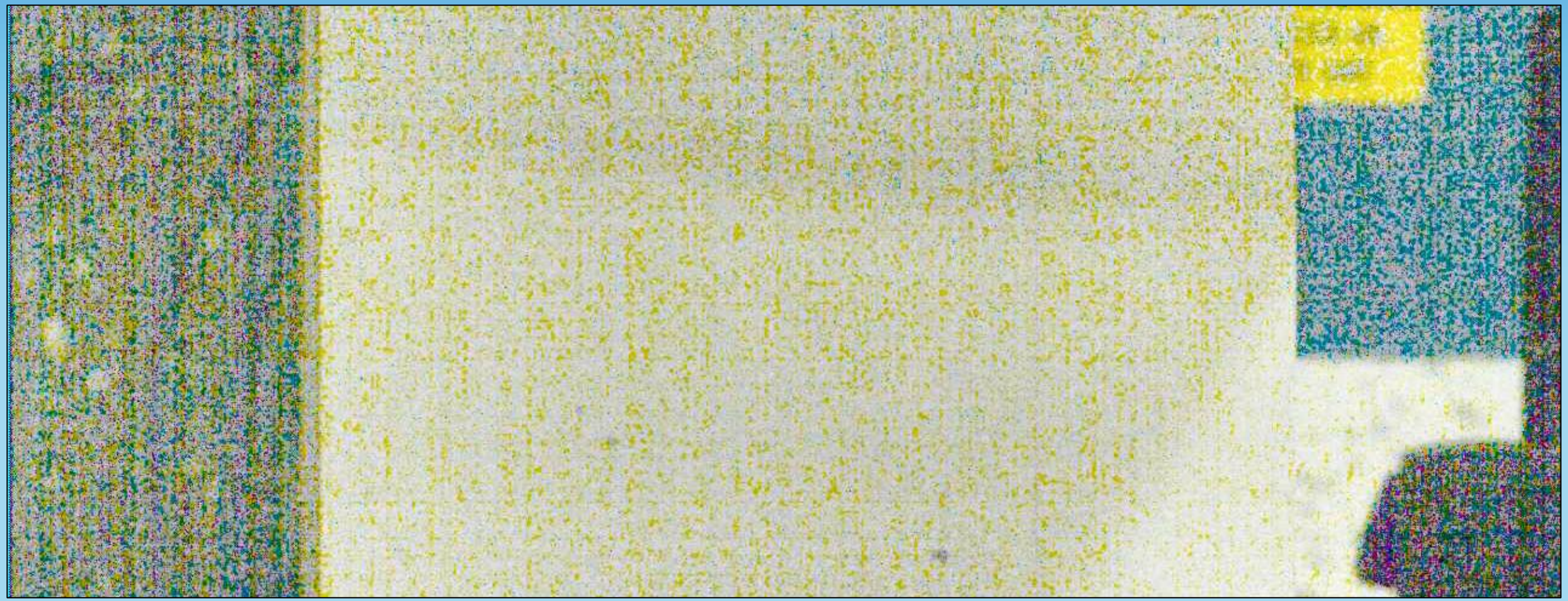
j) Two-Person Rule – Working alone prohibited

k) Environmental considerations – Temperature, humidity, particle counts

l) System Safety – Interface safety review for software bugs, logic errors

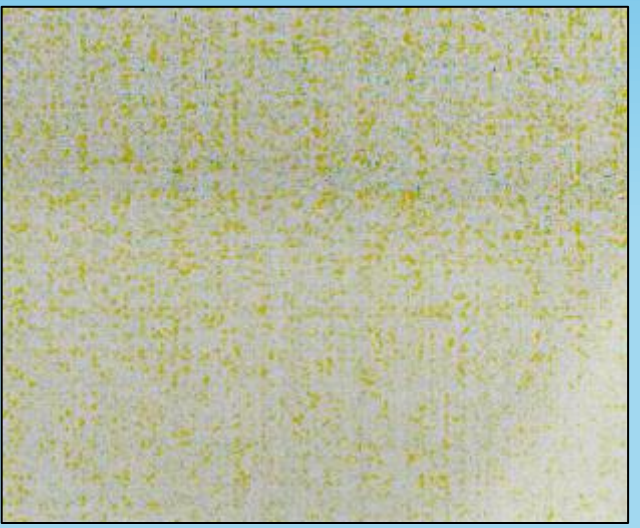
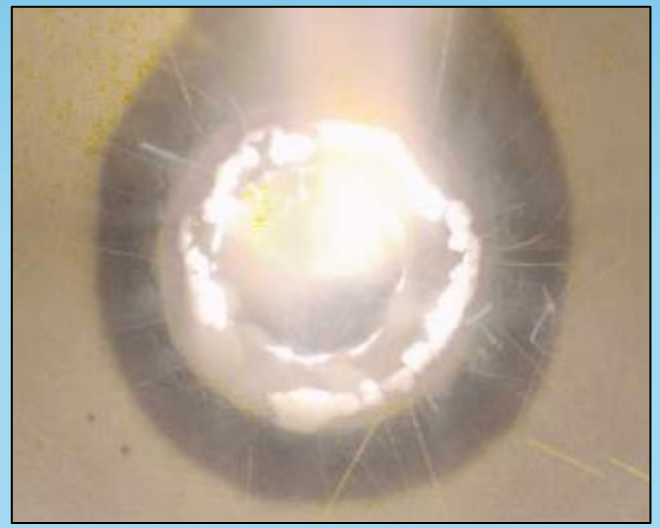
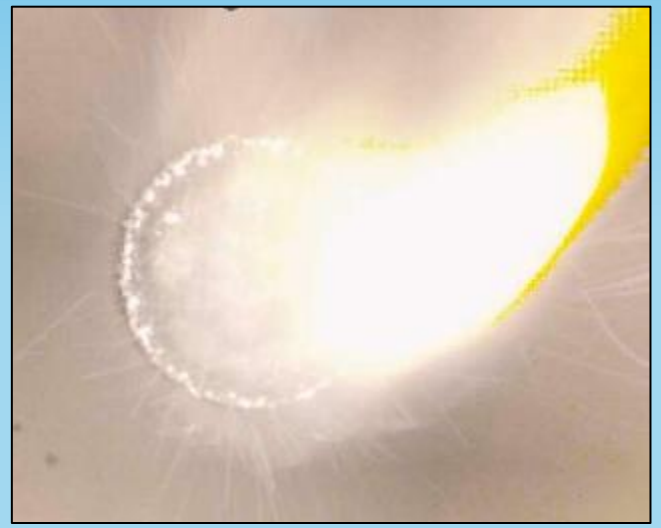
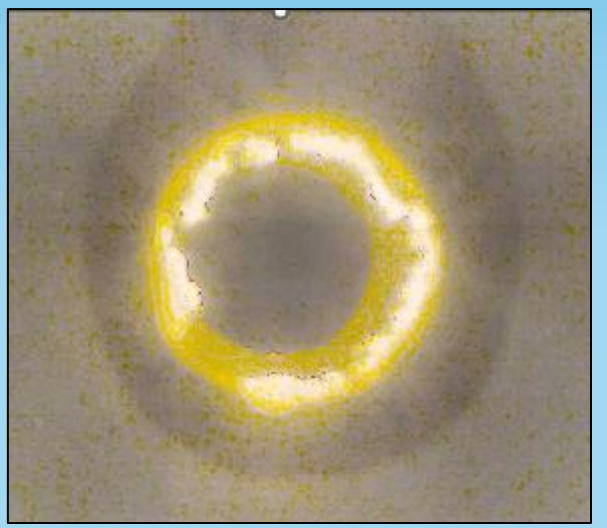
m) Failure Modes & Effects Analysis – Machine, personnel safety, address risks

What Would This Do To You?



Burn-through of drywall with 50kW laser in one second!

What Would This Do To You?

Burn-through of drywall with 50kW laser in one second!

Is This View of the World Worth the Risk?

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Email: Lawson37@llnl.gov

Thank you for your time! Feel free to reach out for further discussion.