SLAC's 2009 Laser Accident

Causes, Lessons Learned and Corrective Actions

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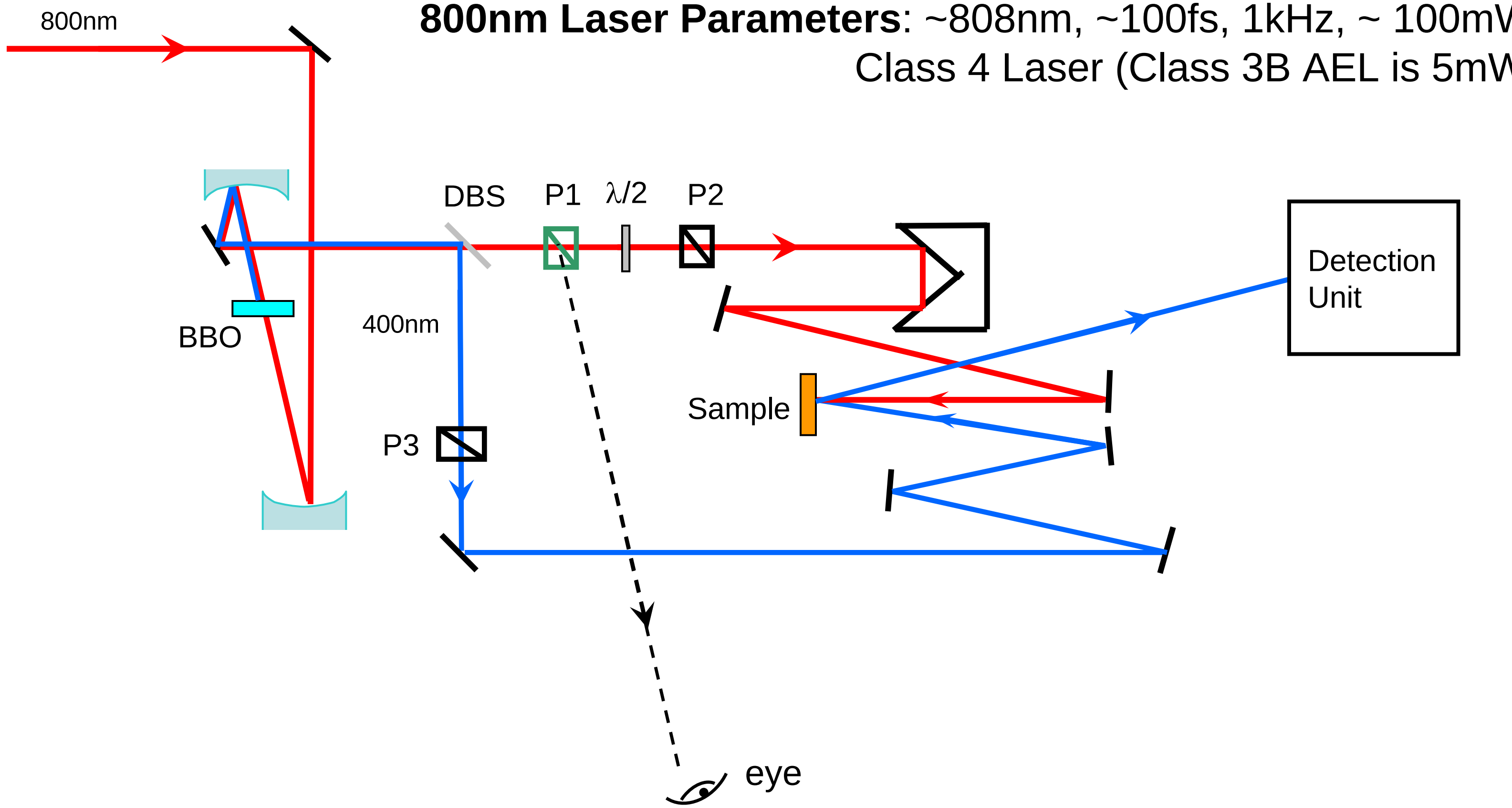
SLAC NATIONAL ACCELERATOR LABORATORY

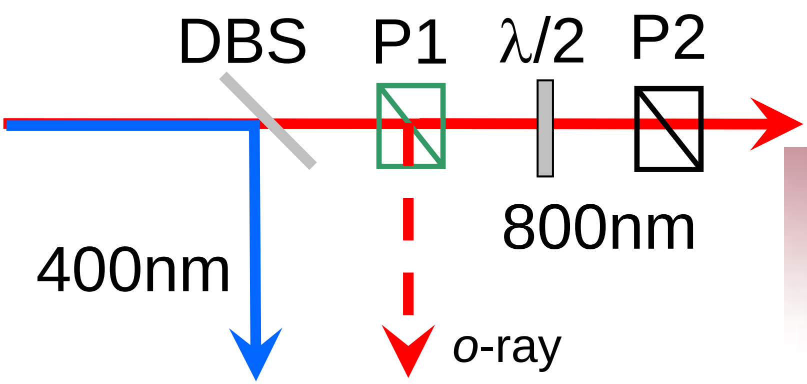
Experimental Setup in Research Laser Lab

800nm Laser Parameters: ~808nm, ~100fs, 1kHz, ~ 100mW
Class 4 Laser (Class 3B AEL is 5mW)



Accidental reflected stray laser beam from P1 polarizer hits unprotected eye of laser operator, during alignment of P1.
Laser operator working alone in lab at time of accident.

Laser Accident Description



P1 has 3 components:

- Polarizer with escape window
- Beam tube with escape window
- Rotating mount

- Initially, beam tube was secured to block the o-ray, which is not used in experiment.
- Laser operator wanted P1 polarizer to be orthogonal to incident laser beam and removed eyewear to co-align back-reflected beam from polarizer with incident beam. To do this, operator loosened polarizer and associated beam tube in the rotating mount.
- Operator then wanted to get polarizer rotation angle oriented to match 0-degree marking on rotation mount.
- Accidental exposure happened when operator rotated polarizer in a way that the escape windows of the polarizer and beam tube aligned, permitting the o-ray to strike their unprotected eye.

Hazard Controls that would have prevented accident

Engineering Controls:

- Use a beam tube with no escape window
- Avoid mounting polarizers in rotating mounts, unless absolutely necessary. Instead, use half waveplates to rotate polarization vector and keep both transmitted and reflected beams in horizontal plane.

Administrative Procedures:

- For aligning polarizer normal to beam, can use 3 methods with full protection eyewear:
  - IR sensor card with a hole in it; incident beam goes thru hole and view back reflection on sensor card as polarizer pitch and yaw are adjusted
  - cut an IR card so can have a straight edge of sensitive IR card close to the beam
  - use an iris and IR viewer to see back reflection on the iris
- For performing optics adjustments when there's no need to observe the beam, block the beam upstream
- Not necessary to have polarizer axes oriented at 0-degrees on rotation mount, so don't perform unnecessary optics adjustments where laser beams are present.

PPE:

- wear full protection eyewear as required by SLAC policy and the SOP

Direct Causes

- Inadequate administrative controls/procedures
  (not practicing safe alignment techniques)
- Not wearing required laser eye protection PPE
- Deficiencies in engineering controls
  (poor selection of optics hardware configuration to block stray beam from polarizer)

Root Causes

Root Causes

1. Inadequate training, in particular On-the-Job Training (OJT)*
2. Inadequate Supervision*
3. Inadequate Work Planning and Control
4. Inadequate adherence to requirements
5. Deceptive hazard of a dimly visible beam
6. Inadequate appreciation of out-of-plane beam hazard in using a polarizing beam-splitter
7. Inadequate intervention following (prior) PPE safety violations

*Some relevant notes about the experimental team that included the injured operator

- injured laser operator was a Stanford graduate student, working as a user in another group's laser facility.
- the injured operator was part of an experimental team consisting of 2 grad students and a postdoc; the postdoc was very experienced as a laser operator, but the grad students did not have very much laser experience.
- they started setting up their experiment at the end of July 2009. At the end of August 2009, the postdoc left SLAC for a new position.
- The thesis advisor for the students is not a laser operator and does not have laser expertise.

Accident Timeline & Lab's Response

9/24/2009

- injury to Stanford graduate student, working alone at time of accident
- Student seeks medical attention at SLAC's medical office who refers him to a local opthamologist
- LSO removes key that permits laser operation in lab where incident occurs
- SLAC management informed of accident
- LSO meets with injured student and some of the lab's laser operators; discuss what happened with accident
- Student reports there is a small blind spot in peripheral vision; there was initial discomfort but not at time of meeting with LSO
- Injured student writes a description of the accident
- LSO informs all SLAC laser operators of accident

9/25/2009

- Lockdown of laser lab where accident occurred
- SLAC management issues stop work order for all research laser facilities; 2 production facilities for accelerator operations are allowed to continue
- SLAC management initiates "Type B-like" investigation
- Mandatory meeting for all SLAC's laser operators
  - ❖ LSO presents description of what is known about the accident and its direct causes, based on the injured student's description and lab visit
  - ❖ LSO presents restart process: requirements for i) re-authorizing laser facility operation, to include a review by facility's laser supervisor and an external reviewer of facility SOP, most recent LSO inspection summary report, and to include a site inspection; and for ii) re-authorizing laser operators, to include additional training
  - ❖ Discussion with operators, line management and ESH/LSO on details of accident, impact on laser operations and research and on restart process

Accident Timeline & Lab's Response

9/28/2009

- LSO convenes OJT and laser supervision review committees.
- Made decision to create ESH 253PRA, laser alignment practical course. Mandatory course required prior to laser operators resuming laser alignment work.

9/30/2009

- LSO gives first ESH 131 class, Laser Accidents & Lessons Learned

10/2/2009

- 253PRA Laser Alignment Practical course completed

10/03/2009

- First laser lab completes all restart requirements (LCLS Injector facility, which is a production facility)

11/2/2009

- External TypeB-like investigation issues its final report with "judgements of need" (focused on lab-wide issues)

1/8/2010

- LSO issues memo on internal assessment of corrective actions for SLAC's laser safety program; it includes 21 corrective actions, 10 of which had been completed at that time (all but one item are complete as of July 2010).

1/29/2010

- LSO issues report to SLAC's OPEX manager on Lessons Learned for SLAC's laser safety program

3/1/2010

- SLAC Corrective Action Plan team issues its report on corrective actions for the lab's programs, to address judgements of need from the external investigation report; corrective actions address broad issues associated with OJT, supervision and facility operations

Corrective Actions and Lessons Learned

1a. Improve core laser safety training:

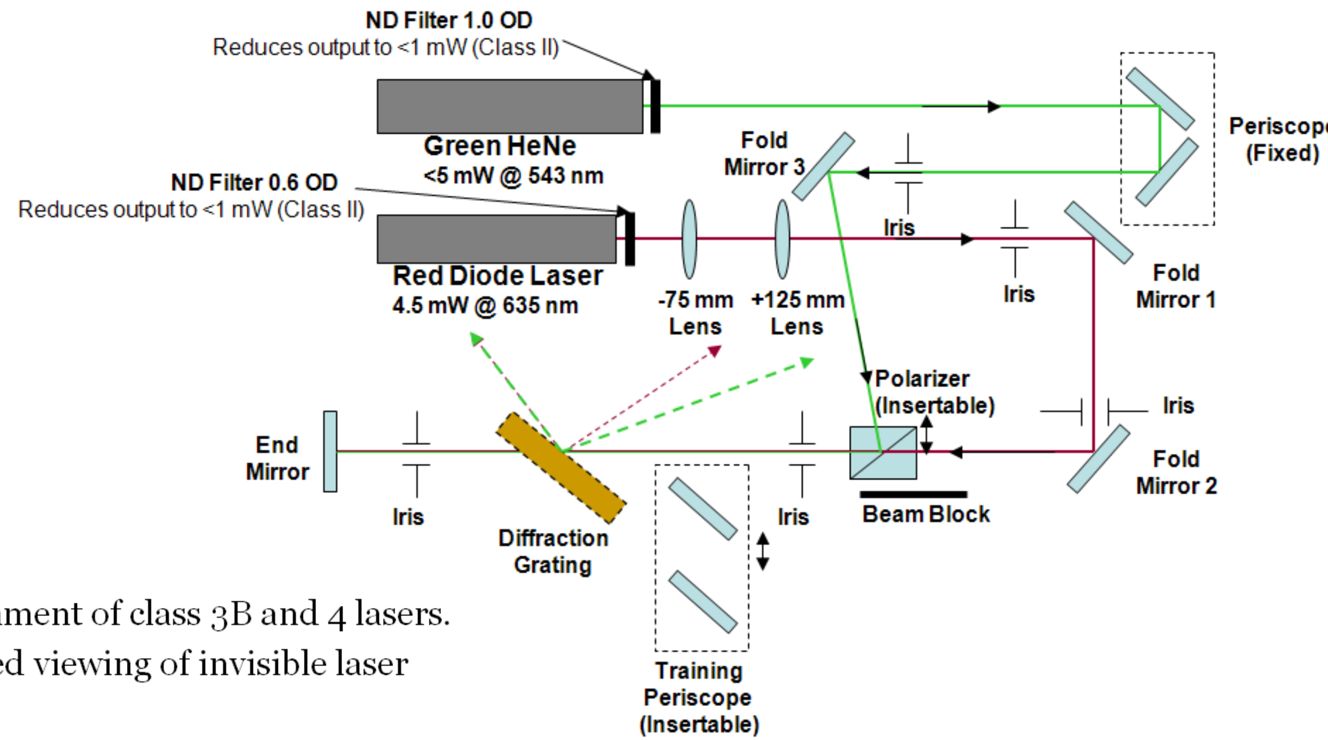
- ESH 131 Laser Accidents & Lessons Learned (new course)
- Revised ESH 253 General Laser Safety course (was planned prior to accident); replaces existing course with a standard DOE course
- Updates to ESH 130 Laser Supervisor Safety course (existing course)

1b. Improve hands-on and site-specific laser safety training:

- ESH 253PRA Laser Alignment Practical; new course that gives standardized practical training that is not site-specific.
  - ✓ Educates students on safe alignment techniques.
  - ✓ Allows SLSOs* to determine skill level of students and determine how much supervision will be needed.
- Site-specific OJT;
  - ➢ guidance to SLSOs on syllabus and documentation for this;
  - ➢ guidance to SLSOs on appropriate training for OJT providers
  - ➢ New template examples now available for SLSOs to implement for OJT syllabus and documenting OJT completion

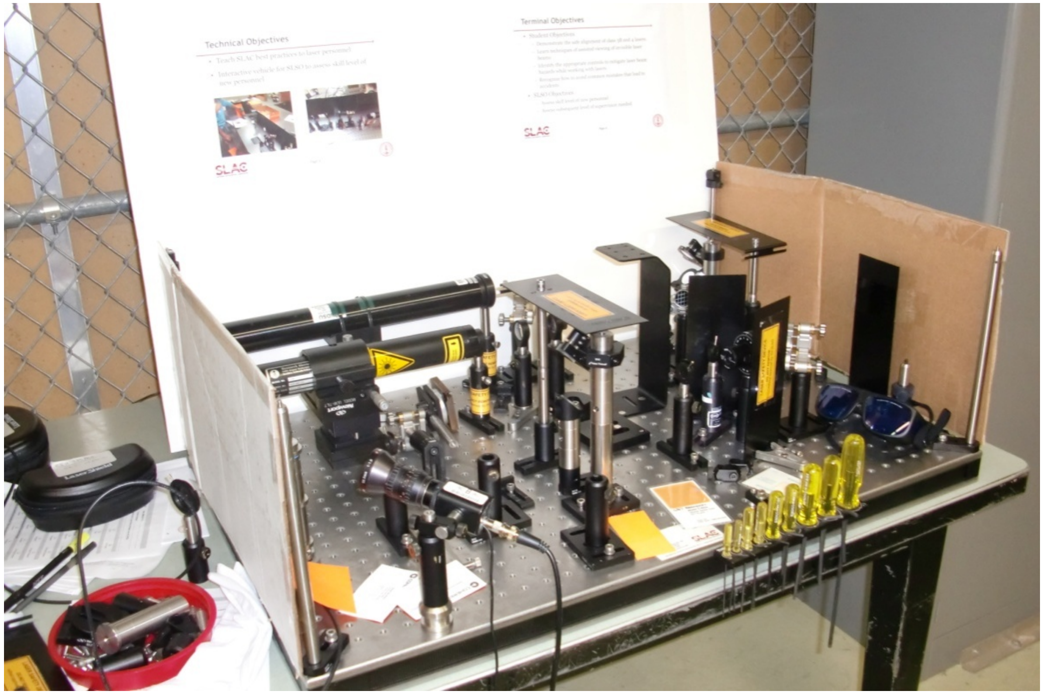
*SLSOs are "system laser safety officers"; these are the laser system safety supervisors, who have direct line management responsibility for safe laser operations in their facilities

OJT Practical Course, ESH 253PRA



- Student Objectives
  - » Demonstrate the safe alignment of class 3B and 4 lasers.
  - » Learn techniques of assisted viewing of invisible laser beams
  - » Identify the appropriate controls to mitigate laser beam hazards while working with lasers.
  - » Recognize how to avoid common mistakes that lead to accidents.
- SLSO Objectives
  - » Assess skill level of new personnel
  - » Assess subsequent level of supervision needed

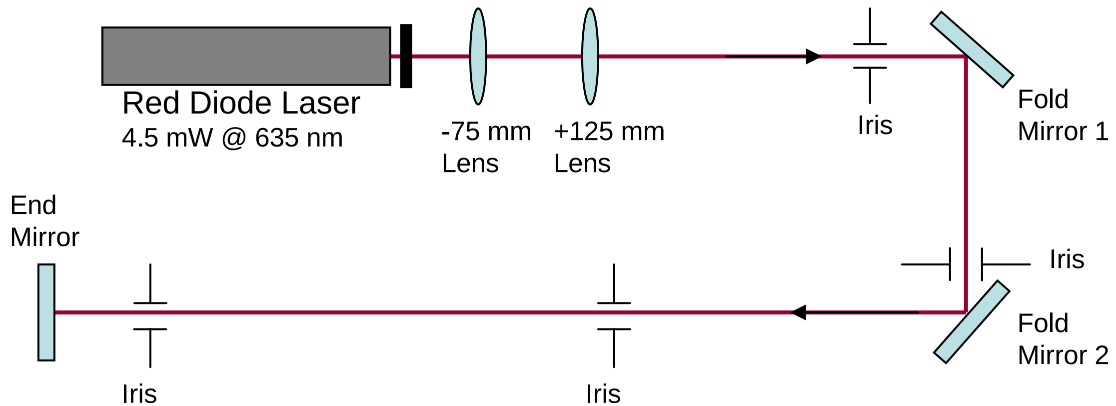
OJT Practical Course, ESH 253PRA



6 Core Exercises

- Beam collimation and telescope alignment
- 2-pinhole alignment
- Periscope alignment with stray beam containment (mandatory)
- Use of beam-splitting polarizers
- Co-alignment of 2 laser beams
- Gratings and diffractive optics principals

Exercise 2: 2-pinhole alignment



Tasks

1. Block or disable the green beam
2. Optimize alignment of the red beam through the two irises using the two folding mirrors after the telescope
3. Optimize the end mirror alignment by observing the back-reflected beam position on the irises
4. Verify all beams and reflected or leaked beams are contained

Tools

Laser safety glasses
Magnetic + fixed beam blocks
IR and fluorescent cards
IR Viewer
CCD camera & monitor

Discussion Points

1. How to chase beam through the beam path with a diagnostic card.
2. How to use an IR card, IR viewer, or CCD camera to verify and set alignment
3. How to properly hold an IR card, such that a reflected beam from it would go down rather than up. Note the reflected beams from the card and the potential hazard.
4. Which back reflections should you be particularly worried about and why?
5. Are there potential leakage points, where?
6. Check for and block any stray beams
7. Try doing this with full protection eyewear on.

Corrective Actions and Lessons Learned

2. Improve supervision and work planning:

i. Roles and responsibilities for laser personnel (LSO, SLSOs, laser operators) updated and emphasized in training; updates include:
   - Guidance for pre-job briefings; can be initiated either by SLSO or QLO*
   - Guidance to SLSOs for site visits to observe and discuss QLO work
   - Administrative (line management) supervisor of QLO may not be the SLSO; in this case, describe roles and responsibilities for adm. supervisor and division of supervision responsibility with SLSO
   - SLSOs and administrative supervisors must hold QLOs accountable for meeting laser safety requirements
   - SLSO and administrative supervisor need to discuss shared supervision responsibilities

ii. Administrative supervisor to sign QLO approval form, and be notified when sufficient OJT is completed that permits QLO to work unsupervised

iii. Guidance for pre-job briefings to SLSOs and laser operators; should be held for:
   - new tasks,
   - unfamiliar tasks or infrequently performed tasks, or
   - when there is a significant configuration change.

*QLO is a “qualified laser operator”

Corrective Actions and Lessons Learned

3. **Improve Work Planning and Control:**
   i. Largely addressed thru improved training and supervision
   ii. Describe role of pre-job briefings in 2 laser classroom courses -- Laser Accidents & Lessons Learned, and Laser Supervisor Safety
   iii. Describe expectations for supervisors and laser operators in these 2 courses; ex. supervisors are expected to:
      - provide good site-specific OJT and good supervision
      - ensure laser facility is well managed
      - perform frequent facility visits and interact with QLOs in their work

4. **Improve compliance with safety requirements in SOP**
   i. Review and stress importance of complying with SOP requirements in laser safety training and supervision;
   ii. Identify and take action to fix inappropriate safety requirements; also facilitate process for this.
   iii. Emphasize that SLAC views PPE violations very seriously

Corrective Actions and Lessons Learned

5. **Address deceptive hazard of dimly visible laser beams**
   - Addressed in new ESH 131 course, Laser Accidents & Lessons Learned
   - This is also addressed in the revised ESH 253 course and should be addressed by SLSOs in the 253PRA course and in site-specific OJT.
   - + see slides 14-15 on this

6. **Address hazards associated with using polarizing beam-splitters**
   (and other optics that may generate out-of-plane beams)
   - Included in 253PRA course and in core laser safety practices OJT

7. **Take appropriate corrective actions and disciplinary actions when there are significant safety violations**
   - Give guidance to SLSOs and LSO for how to address safety violations
     - Important to understand why the violation occurred to determine appropriate corrective action
     - Corrective action may require change in procedures or acquiring new equipment
     - Laser personnel must be held accountable if there are safety violations
   - + see next slide

8. **Develop Performance Metrics for Laser Safety Program, and in particular for OJT and Supervision**

Addressing Safety Violations

slide from laser supervisor safety course

Guidelines to address safety violations by QLOs

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HR Admin guide, "Corrective Action and Discipline"

HR Policy

- expectations that workers carry out assigned tasks and responsibilities, and conduct themselves in accordance with reasonable rules and expectations for the work place
- corrective actions needed if employees don't meet expectations

HR Guidance to Supervisors

i. **Responsibility**
Supervisors are responsible to inform workers of job expectations and requirements, provide appropriate coaching, and give workers opportunity to meet the expectations and requirements.

ii. **Problems and consultation**
Problems do occur and addressing them effectively is an important part of supervision.

iii. **Corrective Action and Discipline**
Examples include:
- Counseling
- Oral warning
- Written warning
- Suspension (temporarily) from performing an activity
- Discharge (for gross misconduct or where attempts at corrective actions have failed)

Note: any disciplinary action for a SLAC employee must involve HR

ESH Course 130 – Safety for Laser Supervisors

SLAC *Creating a Safe, Secure and Sustainable Environment for Science* ES&H

Dimly visible 350-400nm and 700-800nm beams are truly dangerous!

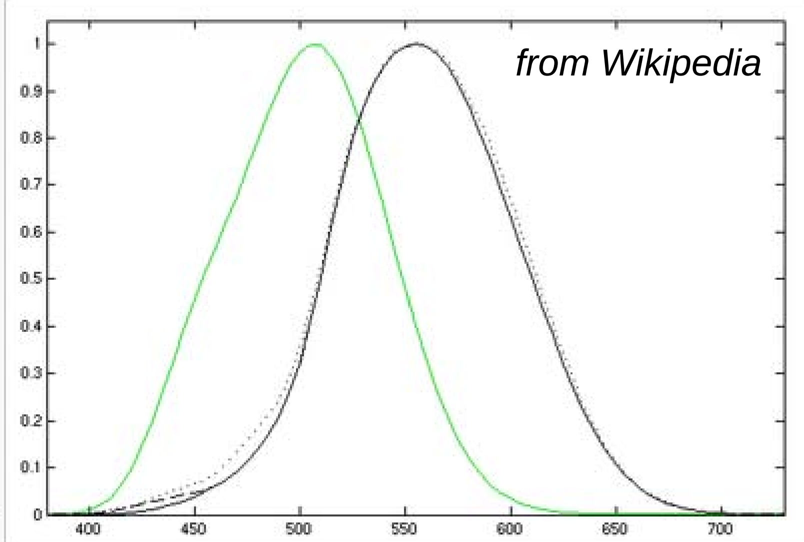
Some laser researchers (and service personnel) have learned that one can
Safely
view some of these beams on a white card
if laser eyewear protection (LEP) is removed.

IF NOTHING GOES WRONG

But this practice is DANGEROUS – diffuse reflection irradiance hazard is typically 10^4 – 10^5 less than the direct beam hazard at 0.5-meter viewing distance. If LEP is removed, typically give up OD5 or more in protection -- diffuse hazard may be ok, but unintended stray beams can be very hazardous.

The danger of these dimly beams is very deceptive. Similar power viewed in the green would likely be scary enough that the researchers would wear LEP.

Luminosity response curves for the eye



Photopic (black) and scotopic (green) luminosity functions.[1] The photopic includes the CIE 1931 standard [2] (solid), the Judd-Vos 1978 modified data [3] (dashed), and the Sharpe, Stockman, Jagla & Jägle 2005 data [4] (dotted). The horizontal axis is wavelength in nm.

Am J Physiol. Vol. **204** p.48 (1963)

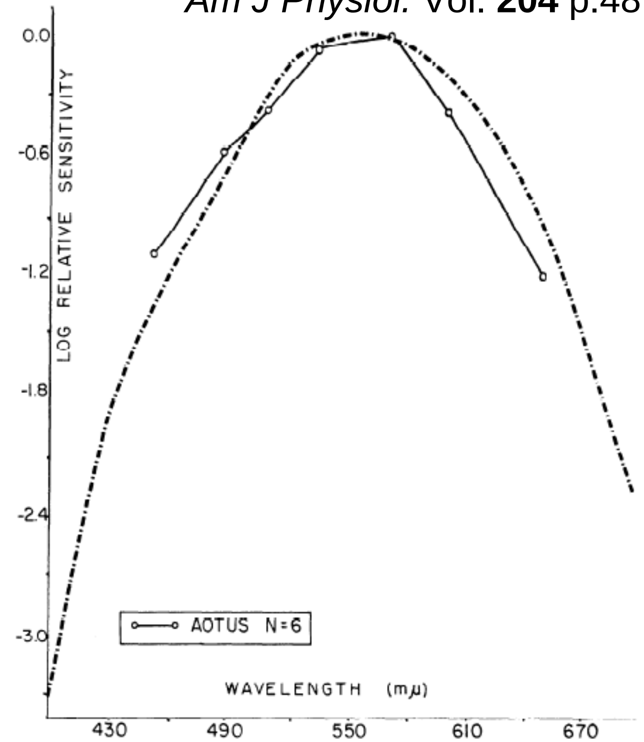


FIG. 3. The photopic luminosity curve for *Aotus* derived from equal response curves for 12- and 20-cycles/sec flickering light. *Broken line* represents the ICI photopic function.

100 mW at 700nm will appear to have similar brightness as
1 mW at 550nm

Performance Metrics

1. **Statistics on laser facilities and laser operators**
   - # facilities, lasers, operators
2. **ESH Core Courses Training**
   - # students completing each training course
   - # employee laser operators with training overdue
   - Course evaluation questionnaire:
     - ✓ Are course materials comprehensive and complete?
     - ✓ Will course adequately prepare student for job tasks?
3. **OJT for site-specific orientation** (questionnaire to laser operators)
   - ✓ Did OJT adequately prepare operator for commencing QLO work?
   - ✓ Was this OJT comprehensive and complete?
   - ✓ How long did this OJT take?
4. **OJT questionnaire for demonstrating core laser safety practices** (required prior to QLO being allowed to perform laser alignment without direct supervision)
   - ✓ Did OJT adequately prepare operator for performing unsupervised laser alignment work?
   - ✓ Was this OJT comprehensive and complete?
   - ✓ How long did this OJT take?
   - ✓ How much expertise was operator identified to have in 253PRA class?
5. **Supervision** (questionnaire to laser operators)
   - ✓ Laser operations and laser safety are well managed?
   - ✓ SLSO interacts effectively with the facility's laser operators?

Summary

Multiple failures in administrative, engineering and PPE controls were the direct cause of the accident

The lab's response to the accident was prompt and very strong

- stop work for all research lasers and additional training for all laser operators
- criteria for restart and additional training were quickly established and communicated
- resources made available to improve training
- both internal and external investigations
- corrective actions for lab-wide programs as well as for the laser safety program

Many root causes for the accident were identified, which led to important lessons learned and corrective actions

- SLAC's laser safety program is being significantly improved as a result of the lessons learned and corrective actions