Volume 3
Issue 4

Laser Lessons News Letter


25kW Solid State Heat Capacity Laser burning through solid steel

This issue:

"When dealing with the much higher outputs of today's lasers, serious planning needs to be done upfront to ensure that a worker is not in the path of a dangerous laser beam....Remember, your skin is the largest organ of your body! Separate the worker from the laser beam or even better, remove the worker from the area and operate remotely."

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Introduction

As we all know, Personal Protective Equipment (PPE) is meant to be the last line of defense for worker protection. First, we try to enclose or contain the laser beam (engineered) as much as practical and as close to the beam as possible. We then utilize curtains, post signs, and use procedures (administrative). Finally, PPE (laser protective eyewear, gloves, clothing, etc.) is employed if needed.

When does PPE become insufficient? When do you reach the point where you should utilize remote operation rather than be in close proximity to the beam? There are no real guidelines available in the regulatory standards, and the Class 4 laser (highest classification) covers all lasers from 0.5 watts average power up to whatever current technology allows us to build. As you can see, all Class 4 lasers are not created equal.

In terms of protective eyewear, the breadth of this classification could mean an OD requirement of anywhere from about OD2 to well over OD7. Remembering that this scale is logarithmic, that could mean the difference in required protection factor of over 1,000,000 times!

REFRESHER: Optical Density (OD) is a convenient tool used to describe the transmission of optical radiation through a blocking medium, It is based on a logarithmic scale.

When you are talking about a laser beam intensity that is a million times greater than the Maximum Permissible Exposure Limit, what do you do? This raises the question of when is the laser "too much for PPE?"

Too much for PPE?

When you think about PPE for lasers, typically laser protective eyewear (LPE) and possibly protective clothing comes to mind. The latter usually applies in situations involving ultraviolet (UV) hazards. Typical LPE filters we use are made of polycarbonate. How well will this hold up to a beam irradiance of 10s of W/cm^2 to kw's/cm^2?

What about clothing? For previously mentioned UV hazards, tightly woven garments and gloves are worn. What about for high irradiance laser beams? Should you even have your extremities in close proximity to these?

Studies have been conducted on laser protective clothing for irradiances of up to 2kW/cm^2 by Laser Zentrum Hannover (LZH) in Germany (2013), but the best thing to hit the streets are laser protective gloves rated to just under 5W/cm^2. This type of PPE is usually for applications where hand manipulation is used to move the material. (Figure 1)

Most of our (LLNL) high energy/high power laser work is in the field of Research and Development (R&D). A lot of this work also tests the limits of optics and other components within the beam path. Do you really want


Figure 1. Laser protective gloves. (Courtesy of LZH)

ANSI Z535 Signage:

We are currently transferring over to the ANSI Z535 format for signage.

The “NOTICE” sign is used to address practices not related to personal injury. It shall not be used in place of “CAUTION,” “WARNING,” or “DANGER.”

The “CAUTION” sign indicates a hazardous situation that , if not avoided, COULD result in MINOR or MODERATE injury. It may also be used without the safety alert symbol as an alternative to “NOTICE.”

The “WARNING” sign indicates an imminently hazardous situation that, if not avoided, COULD result in death or serious injury.

The “DANGER” sign is used to indicate an imminently hazardous situation that, if not avoided, WILL result in death or serious injury. This signal word is limited to the most extreme conditions.

to be near a laser beam that may create a catastrophic failure of an optical component? Rephrased, do you really need to be near an operating laser beam where there are 10s of kW average power or pulse energies in the 10s of Joules per pulse?

This author presented a paper at the 2013 International Laser Safety Conference proposing a new classification (Class 5) to help with controlling very high power laser hazards. A breaking point was proposed between High Power (Class 4) and Very High Power Lasers (Class 5). The classical definition for a high power laser is one which may start a fire and is a diffuse reflection hazard to the skin and eyes. The proposed definition for very high power lasers would be that which may cause serious bodily harm and whose beam interaction with another material would cause dangerous levels of ionizing radiation.

Using this as a rule of thumb, it would also define the level at which you should consider whether it is safer to just not be in proximity to the propagating laser beam.

Let’s look at this from regulatory guidance documents. Under the ANSI Z136.1 (2014) revision, the posting of Laser Controlled Areas (LCAs) has been brought in line with the ANSI Z535 standard for use of the words “Caution, “Warning,”~~,~~ and “Danger” (left panel).

REFRESHER: Laser Controlled Area (LCA) - A laser area where the occupancy and activity of those within is controlled and supervised. This area may be defined by walls, barriers, or other means. Within this area, potentially hazardous beam exposure is possible. (right panel)

Under the 2014 revision, “Warning” will be used for all Class 3B and some Class 4 LCAs. This is a huge change as we are used to seeing “Danger” wording on everything from Class 3a/3R up through Class 4.

The revised standard states that the word “Danger” shall be *restricted* to those Class 4 lasers with high (e.g., multi-kilowatt) output power or pulse energies with exposed beams.

For Clarification: “CAUTION” will be used for Class 2 and Class 3R (previously Class 3a). “WARNING” will be used for Class 3B and some Class 4. “DANGER” will be reserved for the most hazardous of the Class 4 lasers. (See left panel)

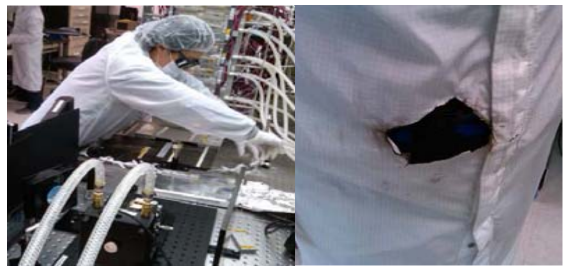


Figure 2. The result of working over a high power laser source

At LLNL we are beginning to move to the use of this new signage and will reserve the use of “Danger” for those lasers that are ≥10kW average power or ≥10J/pulse. These numbers were derived through discussions with our laser user community on where they feel extra care needs to be taken in operational safety. Needless to say, these higher output lasers require higher levels of engineering controls. Many of which are not commercially available.

Looking at the PPE aspect of these higher output lasers, it can vary significantly depending on Facility. There are some Facilities that will not allow personnel access to LCAs where OD> 6 LPE is required. Commercial eyewear vendors no longer rate LPE higher than OD 7. If you still have some older LPE around, you know that it was not uncommon to see ratings of well over OD 10 and even some at OD 20.

Let’s think about this for a minute. Say we are using a 1064nm pulsed laser (10J/pulse, 10E-9s pulse length, 10Hz). This laser requires an OD>7 LPE with an ocular Maximum Permissible Exposure (MPE) limit of 1.58E-5 W/cm^2. The skin MPE is 1.00 W/cm^2. This means that the laser beam is 1000 times greater than the skin MPE. Recalling the limits of the previously discussed commercially available PPE gloves, we see that they are no match (5W/cm^2) for this laser beam.

If you recall a lesson learned that was covered in Volume 1 Issue 2, an individual working in an R&D lab was spared injury, but not their smock, when it was burned by the leakage of fibers carrying approximately 1kW of laser light. (Figure 2) This was just the leakage from a kW total power! The story would have been much different had the full kW struck this individual. Just think what 10kW would do.

So what should we take from this? When dealing with the much higher outputs of today’s lasers, serious planning needs to be done upfront to ensure that a worker is not in the path of a dangerous laser beam. Just because you are in possession of LPE that may have the capability to stop a high powered laser beam from striking your eye for a short period of time, it does not provide a “force-field” to keep your whole body safe.

Remember, your skin is the largest organ of your body! Separate the worker from the laser beam or even better, remove the worker from the area and operate remotely. BE SAFE!

Ten Years of DOE Laser Safety

(Jamie J. King)

Due to a rash of serious laser accidents from 2001 to 2005, including six eye injuries, the Department of Energy (DOE) released a Special Operations Report (SOR) in February of 2005. A root cause analysis revealed that there were four primary causes for the accidents. They were: inadequate training, inadequate Laser Safety Officer (LSO) conduct, need for better internal oversight, and a failure to wear PPE.

Insufficient training and an inadequate level of understanding of the hazards and controls were cited in each of the accidents analyzed. This was noted at the worker level, with those who oversee the operations, and supervisors of laser users. As many of the accidents involved students, the inadequacy or lack of training and a safety culture at the university level was mentioned.

The SOR reported that, while technology continues to advance, the LSO program had not kept pace. Most LSOs were part-time and did not hold the primary function or discipline as LSO. Training for LSOs was often generic and could be described as one-time and "one size fits all." There was no refresher training to help the LSO keep pace with laser technology and changes in regulations. Many were not performing their duties in line with all of the ANSI Z136.1 requirements. Another weakness uncovered was that though the DOE is a singular complex, each Laboratory is independently operated with independent laser safety programs. There was no networking between LSOs and all best practices were being rediscovered by each facility's LSO. Each LSO was basically "reinventing the wheel" when it came to solving complex laser safety issues.

The report cited line management's oversight of laser operations was a contributing factor AND that periodic assessments of lasers, when they did occur, were inadequately documented or lacked sufficient rigor, formality, and follow-up. LSO inspections/audits either had not been conducted since the lasers were installed and granted operational status or had been inspected very infrequently.

A failure to wear PPE was cited in each of the seven accidents that occurred. Remembering that PPE is the last line of defense, how could this happen? In every single one of the accidents, the laser beam was either not where it was supposed to, or intended to be. In situations where LPE is not worn, taking a shortcut is often the reason. The excuse given is that the individual thought that they could better "see" the beam without eyewear on. This is especially true with the lasers in the near infrared (750-800nm).

How does a strong safety program fail? Everything in life works in cycles. Take a look at anything and there are peaks and valleys (like a sine wave). You are left scratching your head wondering how the valleys happened, even with lessons learned. (Figure 3)

Speaking from experience, the cycle from the x/y axis origin point (calibration point) to the area where there is a probability of an accident (danger) is typically a 4-7 year period. This may be shorter or longer with many variables contributing.

The "calibration point" is that point in time where everything is zeroed. This is usually just after a serious accident when management takes action. The typical shape of the curve is not a true sine wave as the slope upward is usually very dramatic and the slope down gradual until it hits a point, like the edge of a cliff (dotted curve) then rapidly ascends.

The slope upward is usually very steep. Here, management provides the backing and commitment (time and funding). This rise is even more dramatic immediately following an accident where a serious injury occurred. This is because all work has been halted as the investigation is completed. People are "shocked" into reality and the invincibility cloak is pulled away. The thoughts of, "that could have been me" are present in everyone's minds. At the peak, everyone has bought into the program and safety truly is "first and foremost."

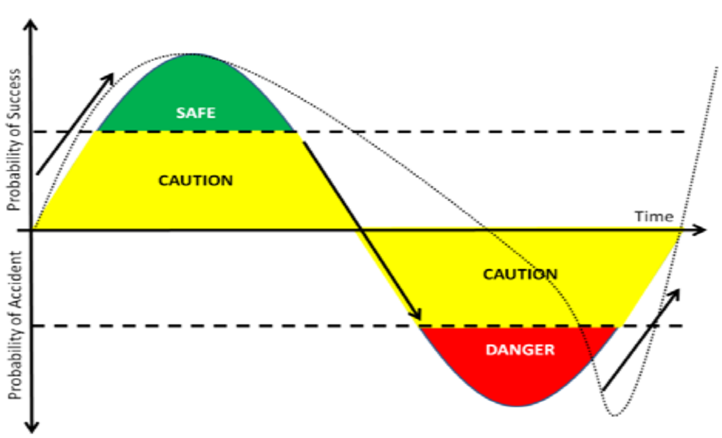


Figure 3. Cycle of program success and failure

The decline is something else. Usually you don't detect it until well into the "caution" area. Many things contribute to this decline: apathy, lack of focus, lack of resources, time, etc. The biggest issue here is that the accident is so distant in the rear-view mirror that people start to forget how easily it can happen and put the invincibility cloak back on. Safety becomes just a buzzword and very few are walking the walk.

The fall depends on two factors, management and the LSO. It is your responsibility, as an LSO, to keep management apprised when you find that the program is on the downward slope. You are the eyes and ears and as such are part of the management team. The goal is to keep your program above the x axis if not totally in the "safe" zone.

Today, work is being performed with laser safety officers from several different DOE Labs working on updating a laser safety training course originally developed by LLNL in the early 2000s. This course will reflect the new Z136.1 (2014) revision and will put the Labs more in tune with each other. There is also a strong mentoring program being fostered along with collaboration between the DOE laser safety officers and their academic counterparts. This will ensure that students will be instilled with a strong safety ethic.

As far as networking goes, the DOE held an LSO Workshop six months after release of the SOR and just celebrated its tenth anniversary this past summer at LLNL. This workshop has become the premier source of all things "practical laser safety" and is attended by DOE, other government agencies, academia, and industry.

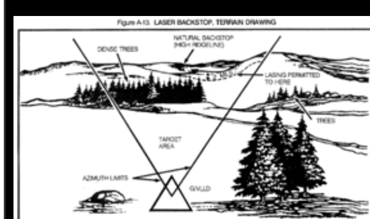
Upon completion of the 5th Annual Workshop in 2009, the Laser Safety Subgroup of the Energy Facility Contractors Group (EFCOG) reorganized and elected officers. This group meets quarterly via teleconference with a face-to-face meeting annually at the workshop. Here, a forum is provided for LSOs from the DOE Labs to share in

Laser Controlled Areas (LCAs):

By control of laser output for altitude (NHZ)

By Locked Panels (Enclosure)

By walls and filtered windows (Room)



By control of area and use of natural backstops

By user control of where they point laser

Uncontrolled, Irresponsible, and ILLEGAL LCA

DON'T DO IT!!!

networking and a common approach to laser safety.

Finally, in relation to the benefits of networking, a subgroup was assembled to tackle a detailed comparison between the ANSI Z136.1 (2000), (2007), and (2014) standards along with the ANSI Z136.8 (2012). This was meant to provide the facts necessary for each Lab to adopt the latest regulatory standard at their facility. This team was just awarded a DOE/EFCOG Team Award for their comprehensive efforts that will be sure to help, not only DOE, but all users in understanding the new standards.

So where are we now? When you take into consideration the several thousand lasers that are in use across the DOE Complex with approximately 4-5,000 of them being Class 3B and Class 4, it brings things into perspective. The use of high powered lasers within the DOE is being performed in quite a safe manner (Figure 4). What should be taken from this and the cycle of accidents is that we must remain forever vigilant. As an LSO, it is your responsibility to keep safety first and foremost in the minds of your laser workers. As shown from the lessons learned in tracking DOE laser related occurrences over the years, accidents don't "just" happen. Safety is a team effort and all must participate for it to work! *(Reprinted in condensed form from "The DOE Special Operations Report on Laser Safety in Retrospect, and Recent Lessons Learned" presented at the 2015 International Laser Safety Conference—J. King)*

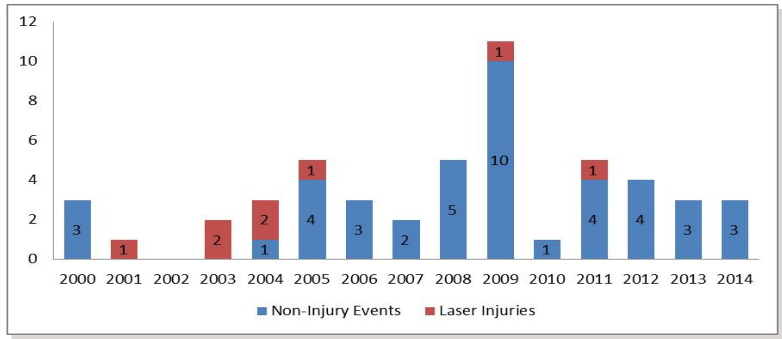


Figure 4. Laser Safety Events (2000-2014)

Lessons Learned

Labeling 3R Lasers and LED Devices

(Courtesy Tekla Staley)

Recently, a facility operations technician at a DOE Lab contacted their LSO about labeling on purchased multi-function flashlights that contain a Class 3R laser. The items ordered were Streamlight Twin-Task 3AAA LASER LED and Multi Ops flashlights. The technician explained that the "Caution" label identified it as a 3R/2 laser/LED with an output <55 mW, and wondered if they could still use the devices.

The LSO recognized that Class 3R lasers should have "Danger" labels and be <5 mW. The technician was instructed to remove the flashlights from service until further information was gathered to determine if the units were safe for use. The product fact sheet showed the product had five (5) ultra-bright white LEDs with an output of 50-100 lumens and a Class 3R laser pointer (650 nm) with an output power of < 5 mW.

The International Electrotechnical Commission/European (IEC/EN 60825-1) standard for Safety of Laser Products, uses the terms 'laser' and 'LED' interchangeably, although LEDs are not lasers nor do they have the same optical properties as lasers. The IEC uses a "Caution" label for Class 3R lasers rather than "Danger" like the United States (Figure 5). You may also notice the triangular yellow label with the laser burst symbol on LED flashlights. Labeling can get quite confusing as most relatively inexpensive consumable products are being distributed with either improper or no labels at all. If you have question with your laser/LED device contact your LSO.

Figure 5. FDA and IEC style laser product labels

Laser Accident

(Courtesy Matthew Dabney, PhD)

On May 5, 2015, a post-doctoral researcher (PR) at a DOE Lab was aligning the beam of an 800nm, femto-second repetitively pulsed, Class 4, Ti:Sapphire laser when he lowered his LPE in order to better locate the laser beam. The PR turned and observed a subtle flash of light strike his right eye. Later in the evening he noticed a blind spot in his vision. On May 6 the PR informed the laser system supervisor of the incident, and on May 7 he reported it to his line manager. After reporting the incident, he was referred to an off-site eye specialist.

This activity started a month earlier with initial planning and setup. The laser's 2.5 watt beam was split sending ~50 milliwatts down a time-delayed leg to three retroreflectors. The mounting fixture was too small to fit three "shielded" retro-reflectors, so the PR installed a legacy "unshielded" retro-reflector in the middle position (Figure 6). The worker forgot to check for stray beams around the retroreflectors.

Significant time passed as the researchers waited for a cryostat to be installed.

On the morning of the accident, the worker and the laser system supervisor (LSS) aligned the system to the cryostat. Prior to beginning the alignment process they did not recheck previously installed optics for stray beams. In the afternoon as the PR was making fine adjustments, aligning the beam through a super continuum-generating crystal, he chose not to use the IR viewer or viewer card used in the initial alignments, as he assumed those tools would not provide him with the visual acuity he needed for the precision alignment task being performed. A neutral density filter had been installed in close proximity to the crystal. This reduced the beam power entering the crystal during alignment, but did not reduce the power of the rest of the system upstream of the crystal. During the alignment task the PR turned his head toward the higher power upstream beam path and was struck in the eye by a stray beam reflected off of the "unshielded" retro-reflector.


Figure 6. Unshielded retroreflector

You can review this scenario and determine direct cause, root causes, and contributing factors. However, in the end, as was discussed in the first article, PPE is the last line of defense. Plenty of incorrect assumptions and decisions lined up to allow this accident to happen. Keep your head in the game, don't take shortcuts and **BE SAFE!**