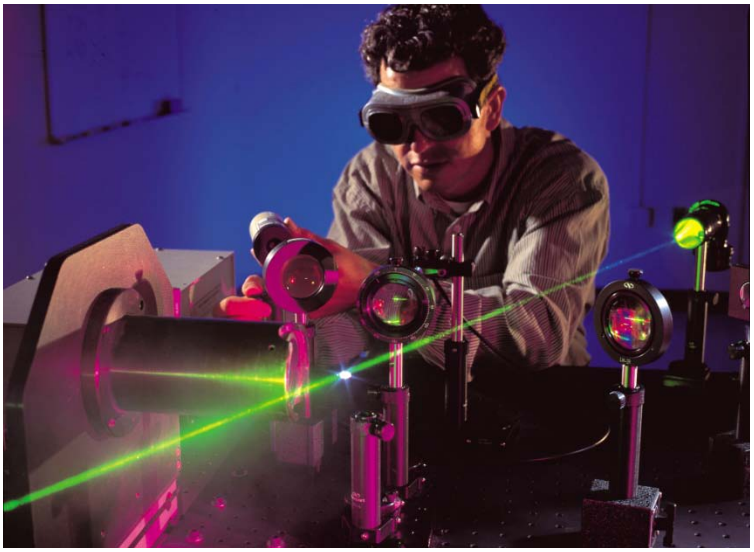
Analysis of

# Laser Safety Occurrences: 2005-2011



Prepared by:

## Office of Analysis (HS-24)

October 11, 2011



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## Summary of Key Observations

The Office of Analysis (HS-24) performed an analysis of occurrence data reported in the Occurrence Reporting and Processing System (ORPS) for the years 2005 to 2011 to evaluate and trend laser safety occurrences. A listing of key observations from the analysis effort is provided below.

1. There were 31 laser occurrence reports reported between January 2005 and September 8, 2011. Twenty-four of these occurrences were Significance Category 3 and three were Significance Category 2. The three Significant Category 2 occurrence reports all resulted in injury.

2. The Office of Science and the National Nuclear Security Administration each had 13 occurrences.

3. Reporting Criteria "Management Concern" was selected 26 times.

4. While Sandia National Laboratories had the most laser incidents (five) from 2005 through 2009, they have had none since.

5. Considering the number of lasers at the National Laboratories (on average 200 Class IIIB/Class IV lasers at each laboratory) there were very few serious injuries.

6. The majority of the injuries and exposures occurred during the use of high-energy laser systems (e.g., Class IIIB and Class IV). One injury occurred at four different sites over the past seven years. Although there were only four injuries during this timeframe, one injury occurred in each of the last three years.

7. Of the 31 laser occurrences, 11 of them involved either intentional bypassing of safety interlocks or the discovery of nonfunctional interlocks. Bypassing engineered safety features or nonfunctional interlocks can result in personnel exposure to laser energy.

8. A review of the five core functions of Integrated Safety Management (ISM) shows that developing and implementing hazard controls was the most frequently cited code, followed by performing work within controls. Defining the scope of work was not seen as a major contributor of laser occurrences.

9. A review of the cause codes for laser safety occurrences showed that Management Problem was the largest area of concern. This was followed by Human Performance and then Communications, which included weaknesses in both verbal and written communication.

10. In the area of Conduct of Operations, the most significant issue was Inadequate Procedures followed by Safety Non-Compliances. In some occurrences, evolutions were performed in which there was no procedure or the procedure did not address important safety issues.

11. Twenty-nine percent of the laser events occurred during, alignment/setup, testing, or maintenance.

# Contents

## Laser Information

There are several thousand laser systems in use to support DOE missions and more than 2,000 of them are Class IIIB or Class IV. 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. Table 1 provides information on the four classes of lasers and describes the laser power and safety concerns for each class of laser.

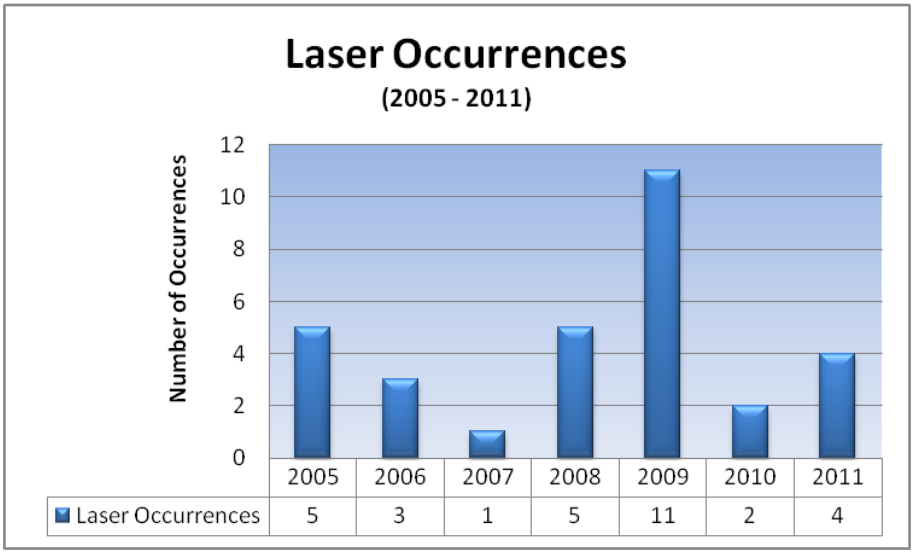
**Table 1. Laser Classifications**

| ANSI Classification | Meaning | Description |
|---|---|---|
| **Class I** (Exempt Lasers) | Safe | Emit low levels of energy that are not hazardous to the eyes or skin. Safe during normal operation, but may contain higher class lasers (a possible hazard only during service or maintenance). |
| **Class II and IIA** (Low-Power Lasers) | Safe for unintended exposure, prolonged staring should be avoided. | 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. |
| **Class IIIA** (Low-Risk Lasers) | Safe when handled carefully. Small hazard potential for accidental exposure. | 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 IIIB** (Medium-Power Lasers) | Wear eye protection within the nominal ocular hazard area. Usually no hazard to the skin. Diffuse reflections usually safe. | 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 IIIB lasers are used in research settings. |
| **Class IV** (High-Power Lasers) | Hazardous - protect eye and skin. Fire hazard. | 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 IV lasers are also a fire hazard, igniting flammable material. |

## Laser Occurrence Reports (2005-2011)

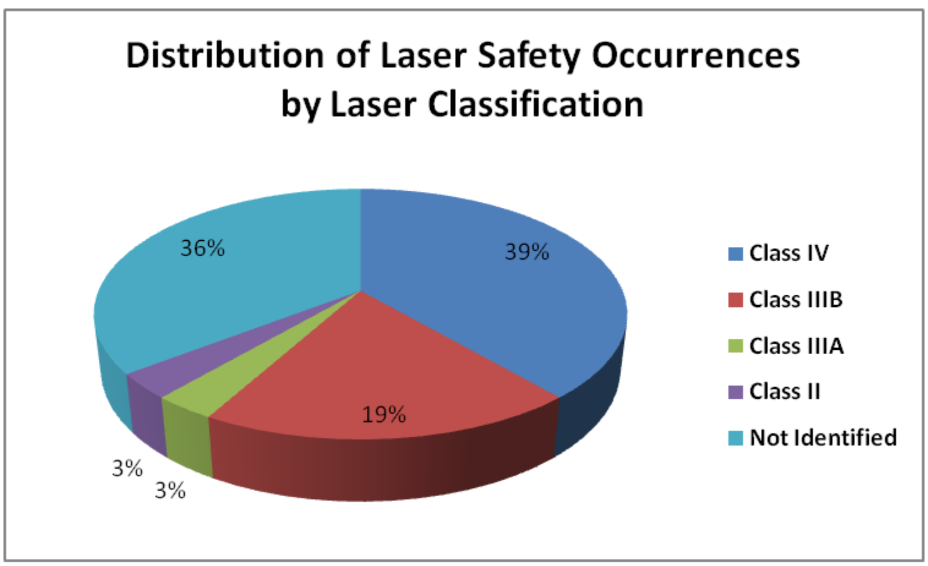
There were 31 laser occurrences reported in the Occurrence Reporting and Processing System (ORPS) database during the period 2005 through 2011, distributed over 13 different sites and 12 different contractors.

**Figure 1. Laser Occurrences from 2005 through 2011**




From 2005, the number of laser events decreased steadily until 2007 and then started to increase to a peak in 2009, which was more than double the number of occurrences in 2005.

**Figure 2. Distribution of Laser Safety Occurrences by Laser Classification**




The majority of the reported laser occurrences (58 percent) involved high-energy laser systems (e.g., Class IIIB and Class IV lasers), which have the highest potential for producing serious injury.

## Summary of Laser Occurrences in 2011

There have been four laser safety occurrences since the beginning of 2011. The following is a summary of these four occurrences.

1. **Pantex Plant**

   On March 17, 2011, following discussions with personnel, Pantex management became aware that a laser beam malfunction had occurred on March 16. A Pantex scientist was using the laser in a facility to perform research activities and the system malfunctioned by discharging the laser beam unexpectedly. The scientist performing research activities had made an adjustment to the duty cycle setting without powering down the laser. The laser is normally powered down before adjustments are made; however, there is no written procedure directing this action. The scientist did not push the fire button; however, the laser fired. Based on past experience and knowledge, the scientist assumed the laser would only fire when the fire button was pushed. The laser system was powered down and the laser key was removed. Applicable laser activities were placed on hold and the system was tagged with a Do-Not-Use tag. A consultant, the laser manufacturer, and the wave form generator manufacturer were contacted. A critique was held. A design flaw in the waveform generator had allowed a continuous pulse to be delivered without pressing the trigger button. The manufacturer was notified of this condition, reproduced the scenario, and got the same results.

2. **Lawrence Berkeley National Laboratory**

   On April 12, 2011, an LBNL Materials Sciences Division (MSD) safety technician entered an active laser laboratory not knowing that the laser was on. The MSD safety technician had entered the Building 2 lab to post a sign. The room was not locked and the ‘laser on’ warning light next to the door was off. Several graduate student researchers were in the room with laser goggles on and they immediately asked the technician to leave the room, advising him that a class 4 laser system was on. The laser interlock system, that controls access to both rooms, had started malfunctioning several weeks earlier. The principal investigator contacted LBNL Facilities personnel to repair the interlock, but the repair was unsuccessful. The labs operated for a time with the shutter portion of the interlock system bypassed. A draft Temporary Work Authorization (TWA) was prepared to allow the lab personnel to operate the laser with alternative control measures until the interlock system was fixed, but the draft TWA was not approved as required. Under normal circumstances, entering a laser lab without using the keypad would have triggered the laser shutter to close and the warning light to turn off, returning the lab to ‘safe’ state. The draft TWA required manually activating the ‘laser on’ warning light whenever the laser was in use. However, when the safety technician entered the room, the door was not locked and the ‘laser on’ warning light was off. Laser operations were suspended. Personnel did not ascertain that manually turning on the existing ‘Laser on’ warning light would work before adopting this process as a temporary compensatory measure. It was later discovered that the interlock light could not be used in this manner due to the way it was designed and the failed keypad.

3. **Stanford Linear Accelerator Center**

On May 25, 2011, a Stanford graduate student was performing optics research in a laser lab, which did not require the presence of laser beams, when he noticed the dimly visible red beam of a Class 4 (high power) 800nm laser on his shirt sleeve. The laser operation mode for the lab was set to Class 1, which means that any hazardous beams are fully enclosed. PPE laser eyewear is not required in this Class 1 mode. The graduate student immediately put in a beam block to shield the laser beam hazard and notified the lab laser safety supervisor. The supervisor then disabled laser operation for the lab by removing the Master Key, which forces LASER OFF operation mode, and notified the SLAC Laser Safety Officer. There were no injuries or equipment damage. Investigators learned that laser operators had made a laser safety configuration change without defining and following an appropriate work plan. The upshot of which is that a laser safety shutter was removed from the beam path and the full functionality of the laser safety system was not restored. This ultimately resulted in a laser beam being present in an uncovered enclosure during a (restricted) operating mode when no beam should have been present. The investigation team found that better safety configuration control and training would likely have prevented the event from occurring. This event also underscores the need to define and follow good procedures with an emphasis focusing on the task at hand, and the importance of on the job training. Moreover, the team found that training and procedures should explicitly include safe methods for zero energy verification.

4. **Idaho National Laboratory**

On August 30, 2011, during the performance of preventative maintenance for a 2,000 hour run time on a Class IV laser, a Specific Manufacturing Capability technician received second-degree burns to the middle and ring fingers on his left hand. Qualified technicians were in the process of aligning the mirrors on a Laser Optics Telescope when the event took place. In preparing to align the mirrors, the electricians selected the program parameters, as instructed in the procedures. They verified the settings within the program and proceeded to install a target by hand into the required location to take a paper shot. This procedure tests the alignment of the laser beam to ensure it is reflecting properly off the mirrors. To activate the invisible beam a technician then steps outside of the nominal hazards zone boundary and, using both hands, turns the key and pushes the button on the hand held pendant. When placing the target into place, the technician's left hand came into contact with an unexpected, unfocused energized 2,500 watt beam and was burned. The high power was immediately turned off by the maintenance Person in Charge and the laser was placed in a safe configuration. The technician was taken to Central Facilities Area medical and was treated for the burns to his fingers and was released to SMC with restrictions. Investigators determined that the technicians lacked a thorough understanding of the Human Machine Interface and mode of laser operation. The work order did not provide specific controls to safely align the laser. Tasks were performed from memory rather than by following procedures. Also, the Laser Safety Officer relied on the experience, skill, and training of the technicians to perform the tasks safely.

## Breakdown of Laser Occurrence Reports (2005-2011)

Figures 3 and 4 provide a breakdown of the laser occurrences by Program Office (PSO), by Contractor, and by Site. The majority of the laser safety occurrences were divided equally between the Office of Science and the National Nuclear Security Administration. The contractor with the most occurrences was the Sandia National Laboratories.

**Figure 3. Number of Laser Safety Occurrences by Program Office**

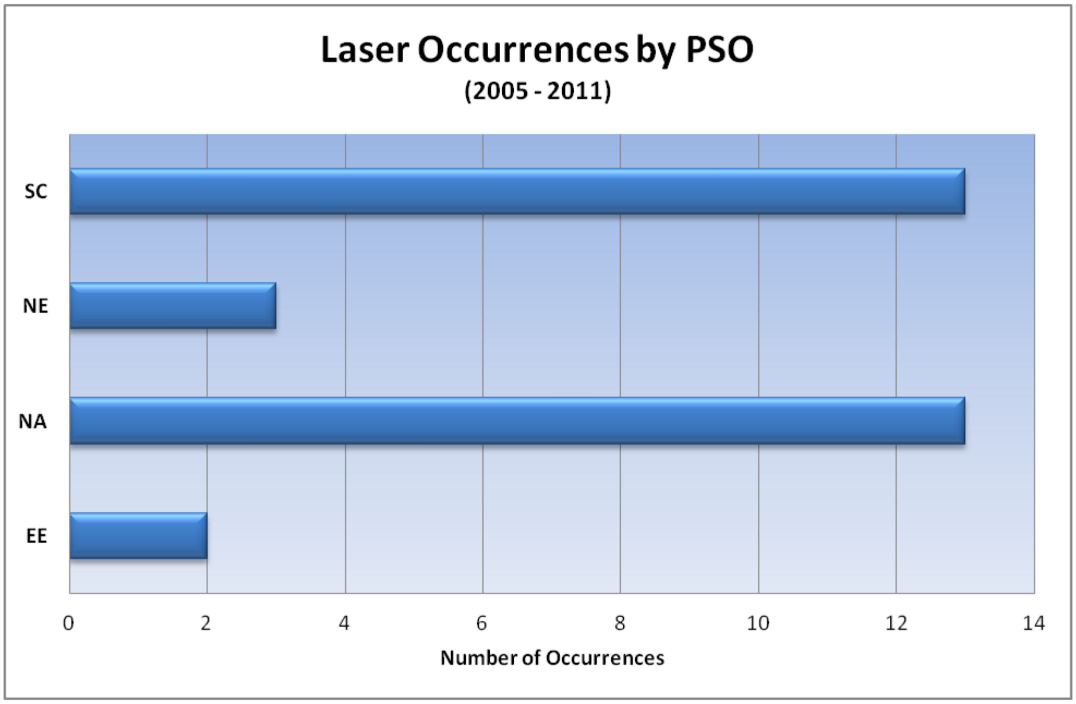



**Figure 4. Number of Laser Safety Occurrences by Contractor**

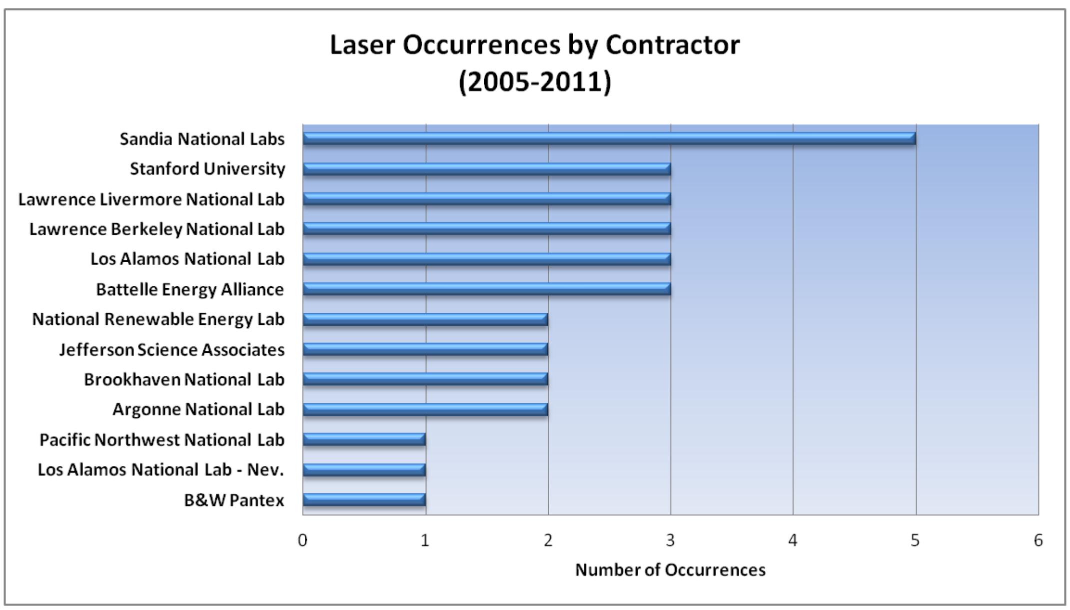
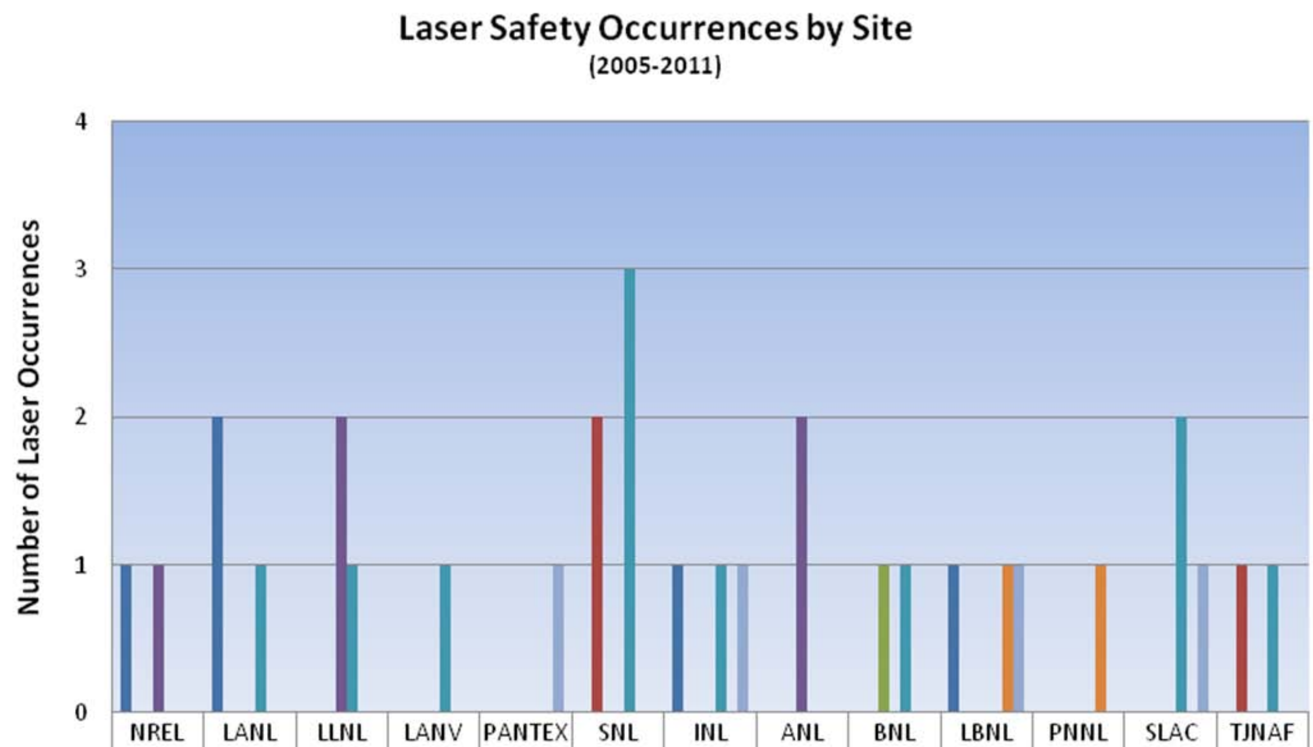


**Figure 5. Number of Laser Safety Occurrences by Site per Year**




| | NREL | LANL | LLNL | LANV | PANTEX | SNL | INL | ANL | BNL | LBNL | PNNL | SLAC | TJNAF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 2005 | 1 | 2 | | | | | 1 | | | 1 | | | |
| 2006 | | | | | | 2 | | | | | | | 1 |
| 2007 | | | | | | | | | 1 | | | | |
| 2008 | 1 | | 2 | | | | | 2 | | | | | |
| 2009 | | 1 | 1 | 1 | | 3 | 1 | | 1 | | | 2 | 1 |
| 2010 | | | | | | | | | | 1 | 1 | | |
| 2011 | | | | | 1 | | 1 | | | 1 | | 1 | |

Figure 5 provides a breakdown of laser safety occurrences by site and by year. The data shows that Sandia National Laboratories reported the highest number of occurrences during the analysis period and their last occurrence was in 2009. The three 2009 occurrences involved the intentional bypass of safety interlocks on laser welders.

The four occurrences in 2011 were each from a different site and don't establish a pattern at any of the sites. Collectively the occurrences indicate a weakness in procedures and the use of engineered interlocks and/or a lack of understanding of their functionality.

## Laser Injuries and Exposures

From 2005-2011 there were four occurrences with reported injuries, six occurrences in which an exposure occurred, but with no injuries, and only one occurrence with a reported fire. The majority of injuries and exposures to hazardous laser energy involved the operation of Class IIIB and Class IV lasers. The most recent injury occurred on August 30, 2011, at the Idaho National Laboratory. This injury resulted in burns to the hands. The following table provides information on these injuries.

**Table 2. Laser Injury Occurrences**

| LASER INJURY OCCURRENCES | | | | |
|---|---|---|---|---|
| **SITE** | **DATE** | **LASER CLASS** | **INJURY** | **HOW EXPOSED** |
| INL | 8/30/2011 | Class IV | Burns to fingers. | Reached hand into beam while placing a target. |
| PNNL | 6/22/2010 | Not Identified (UV Illuminator) | Burns to neck. | PPE did not provide full coverage of exposed skin. |
| SLAC | 9/24/2009 | Class IIIB | Retinal burn to eye. | Was not wearing eye protection. |
| NREL | 1/19/2005 | Class IV | Retinal burn to eye. | Removed eye protection during laser operation. |

There were six laser occurrences in which personnel were exposed to diffused laser light but did not suffer any injuries. Figure 3 shows the distribution of adverse outcomes as a percentage of all laser occurrences and Figure 4 shows the breakout of adverse outcomes by site.

**Figure 6. Distribution of Laser Safety Occurrences by Adverse Outcomes**

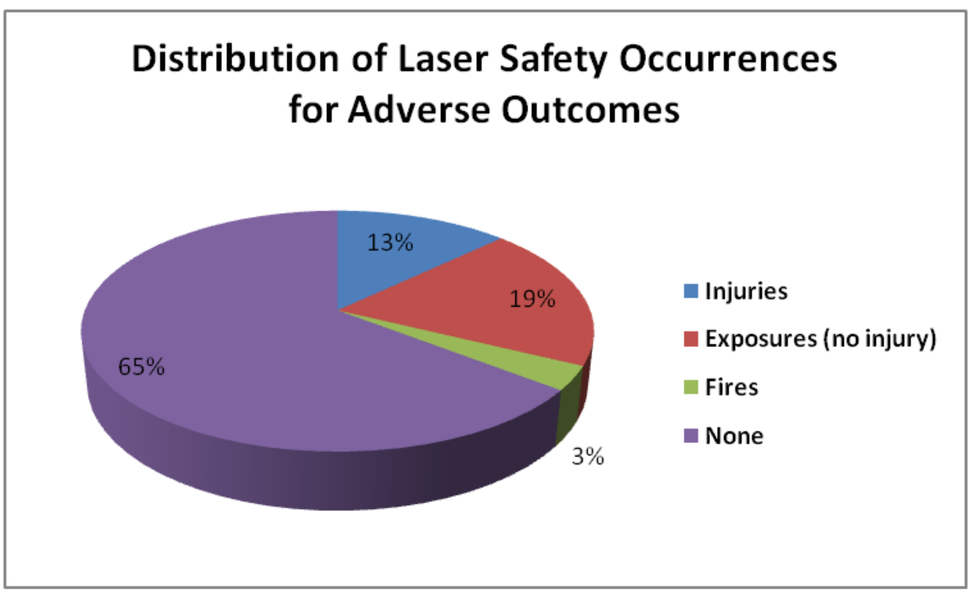





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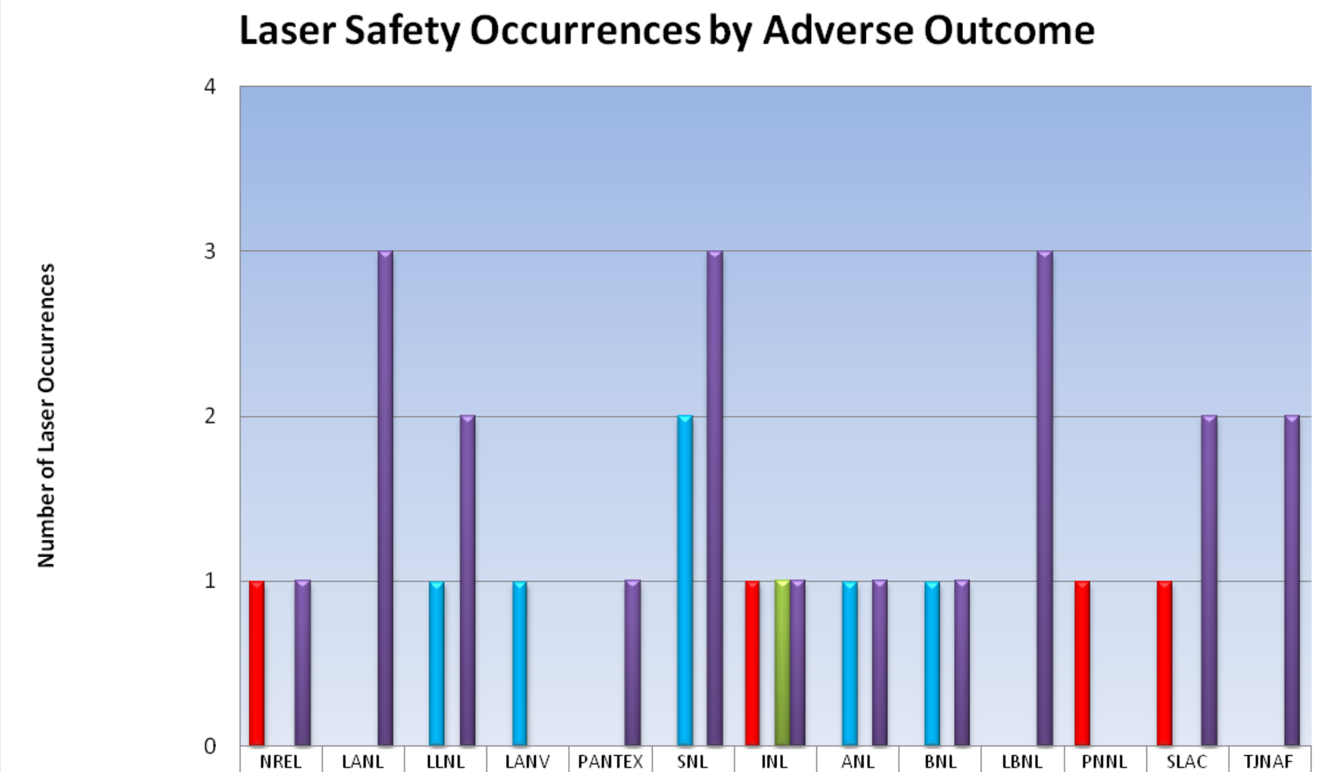
**Figure 7. Adverse Outcomes as Reported by Site**




| | NREL | LANL | LLNL | LANV | PANTEX | SNL | INL | ANL | BNL | LBNL | PNNL | SLAC | TJNAF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Injuries | 1 | | | | | | 1 | | | | 1 | 1 | |
| Exposures (no injury) | | | 1 | 1 | | 2 | | 1 | 1 | | | | |
| Fires | | | | | | | 1 | | | | | | |
| None | 1 | 3 | 2 | | 1 | 3 | 1 | 1 | 1 | 3 | | 2 | 2 |

The data in Figure 7 shows that one injury (caused by exposure to laser energy) occurred at four different sites over the past seven years. Although there were only four injuries during this timeframe, there was one in each of the last three years.

A review of the laser injury occurrences during the previous four years (2001 through 2004) shows that there were five occurrences at four different sites involving retinal burns, with one resulting in the permanent loss of central vision in the left eye. Only one site (Argonne National Laboratory) had two injures.



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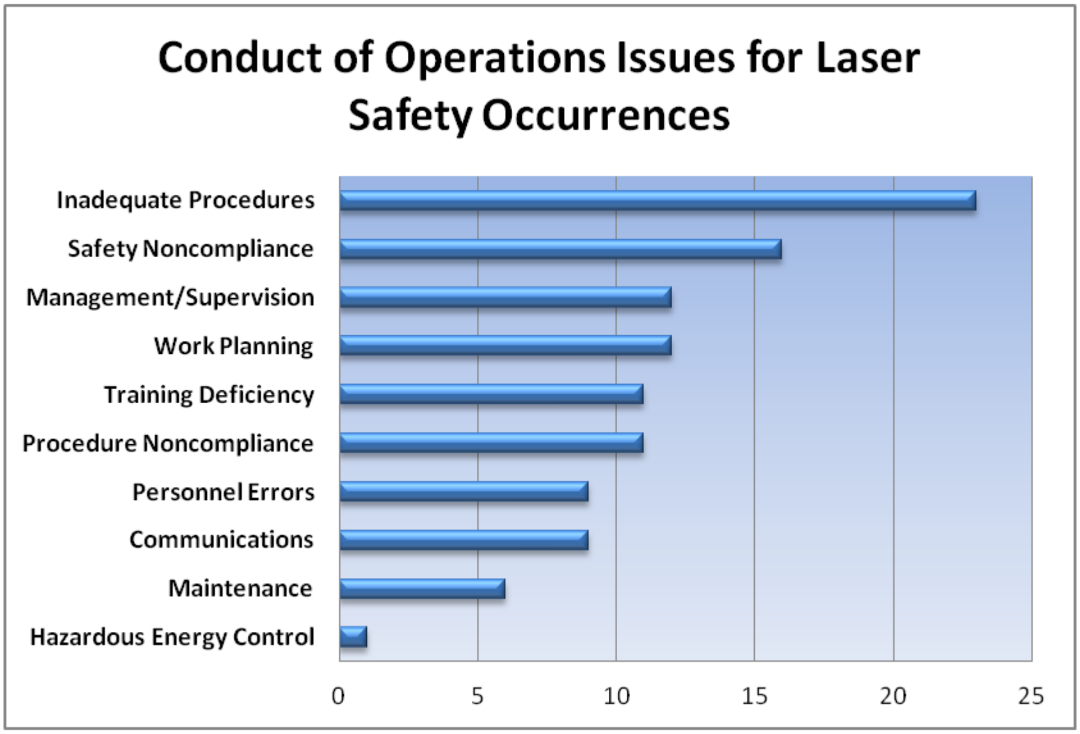
## Conduct of Operations

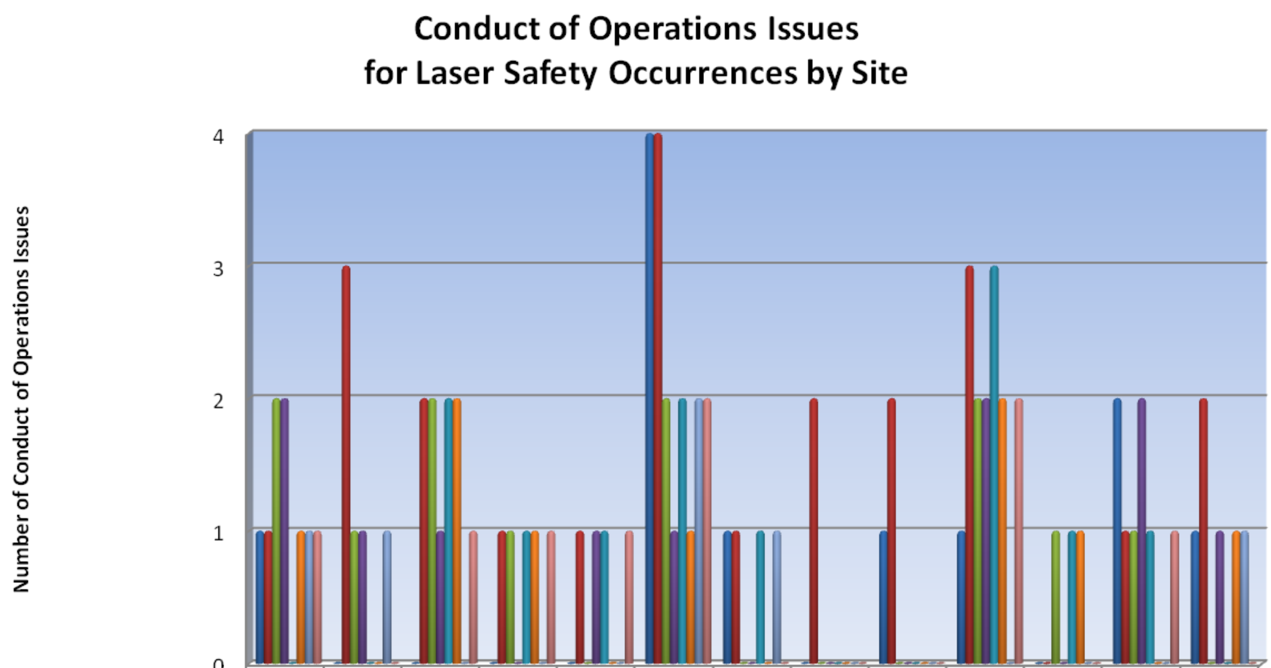
**Figure 8: Conduct of Operations Analysis**




The data in Figure 8 shows that Inadequate Procedures was the most significant issue followed by Safety Non-Compliances. In some occurrences, evolutions were performed in which there was no procedure or the procedure did not address important safety issues.

Note: HQ Keyword for Inadequate Procedure also includes conditions in which no procedure exists.

**Figure 9. Conduct of Operations Issues by Site**




| | NREL | LANL | LLNL | LANV | PANTEX | SNL | INL | ANL | BNL | LBNL | PNNL | SLAC | TJNAF |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Procedure Noncompliance | 1 | 0 | 0 | 0 | 0 | 4 | 1 | 0 | 1 | 1 | 0 | 2 | 1 |
| Inadequate Procedures | 1 | 3 | 2 | 1 | 1 | 4 | 1 | 2 | 2 | 3 | 0 | 1 | 2 |
| Work Planning | 2 | 1 | 2 | 1 | 0 | 2 | 0 | 0 | 0 | 2 | 1 | 1 | 0 |
| Training Deficiency | 2 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 2 | 0 | 2 | 1 |
| Management/Supervision | 0 | 0 | 2 | 1 | 1 | 2 | 1 | 0 | 0 | 3 | 1 | 1 | 0 |
| Communications | 1 | 0 | 2 | 1 | 0 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 1 |
| Maintenance | 1 | 1 | 0 | 0 | 0 | 2 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| Personnel Errors | 1 | 0 | 1 | 1 | 1 | 2 | 0 | 0 | 0 | 2 | 0 | 1 | 0 |

The analysis of conduct of operations execution issues indicates that Sandia National Laboratories had the most occurrences in which either procedures were inadequate or were not followed.



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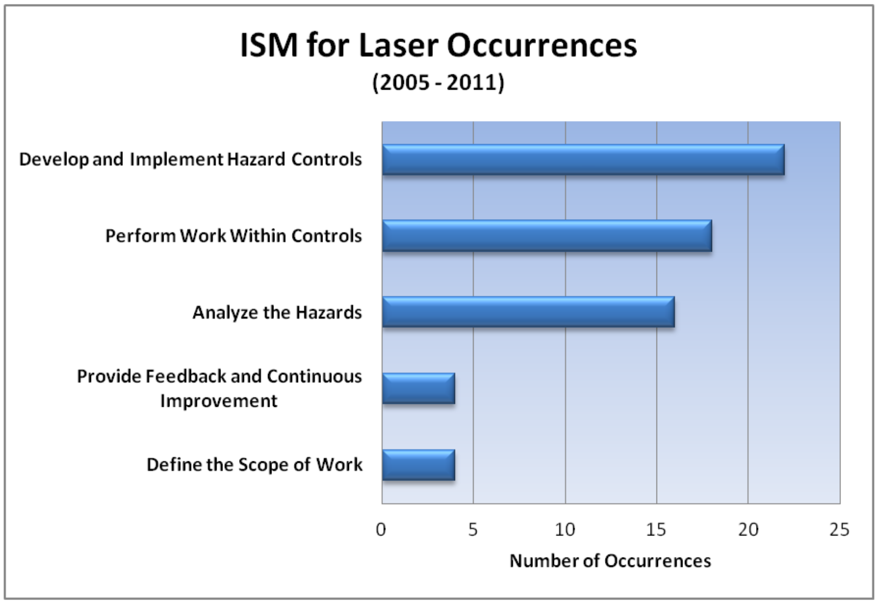
## Integrated Safety Management (ISM)

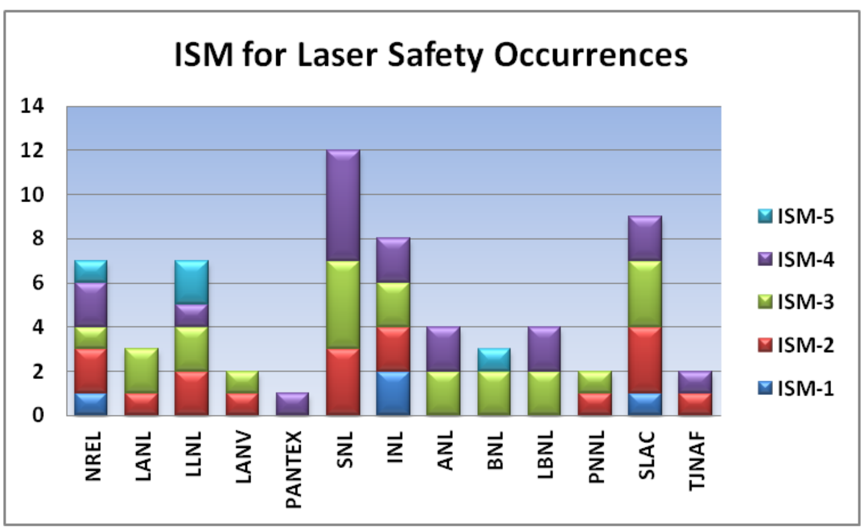
The following chart shows the assignment of ISM codes for all of the laser safety occurrences.

**Figure 10: Breakdown of ISM Core Functions for all Laser Occurrences**




The ISM codes, which were assigned by the sites, show that Developing and Implementing Hazard Controls was the top code, followed by Performing Work Within Controls. Defining the Scope of Work was not seen as a major cause of laser occurrences.

**Figure 11. Breakout of ISM Core Functions by Site**




The data in Figure 11 shows how the ISM codes were distributed for each of the sites.



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## Cause Code Analysis

**Figure 12: Cause Code Breakdown**

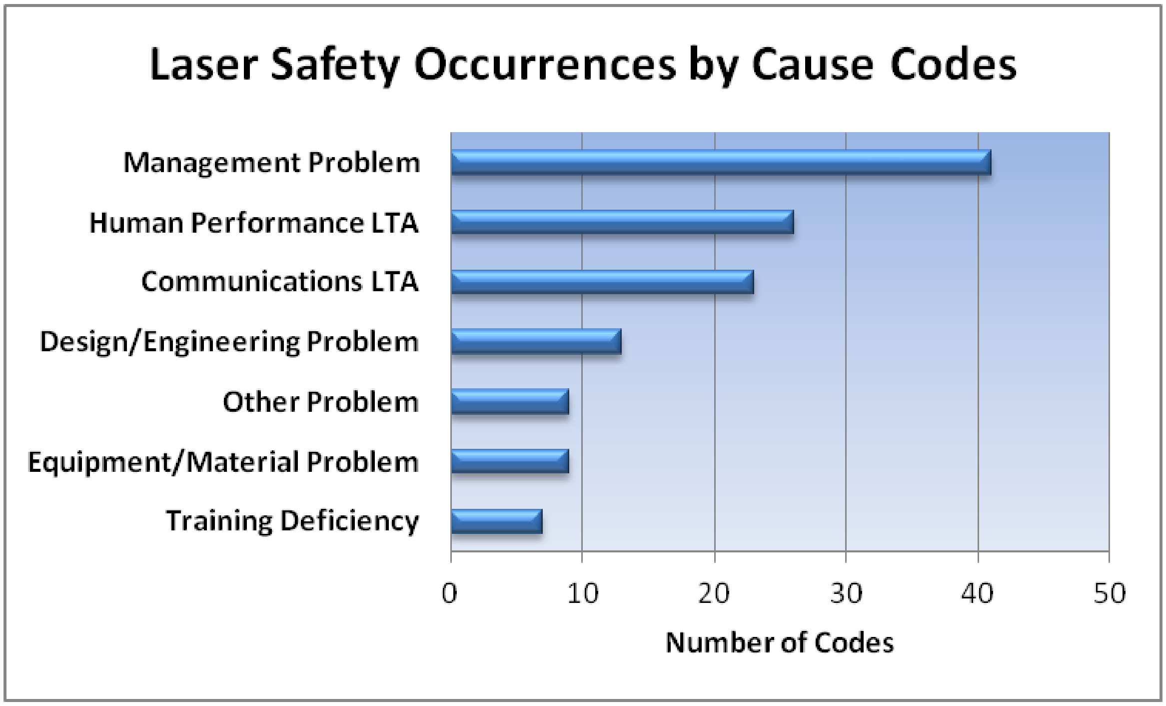


Figure 11 provides the breakdown of the cause codes for laser safety occurrences that were assigned by the sites. Management Problem was identified as the largest area of concern, which included: Management Policy Guidance/Expectations Not Well-Defined, Understood or Enforced; and Job Scoping did not Identify Special Circumstances and/or Conditions. Under the area of Human Performance, the biggest contributor was Skill-Based Errors (e.g., infrequently performed steps performed incorrectly and incorrect performance due to mental lapse or procedure step omission). There were three main areas of concern under the area of Communications. The first area of concern was in Written Communication Content, which had: ambiguous instructions or requirements; or the instructions were incomplete. The second area of concern was the Lack of Written Communications. The third area of concern was less than adequate Verbal Communications Between Work Groups.

# Laser Safety Operating Experience

## Special Operations Reports (SOR)

The following SOR was issued after seven laser accidents were reported in ORPS from 2001-2005 that resulted in eye exposures to six people. The SOR identified four primary common causes that included inadequate training; inadequate conduct of Laser Safety Officers; the need for better internal oversight; and the failure to wear personal protective equipment (e.g., eye protection).

***Laser Safety*** (SOR 2005-01)
http://www.hss.doe.gov/sesa/Analysis/reports/Laser_Safety_Report.pdf

## Operating Experience Summaries (OES)

The following Operating Experience Summary articles address the safety concern of not wearing appropriate eye protection for safe laser operations.

1. ***Using Safety Controls and Appropriate Eyewear for Safe Laser Operations*** (OES 2005-08
   http://www.hss.doe.gov/SESA/Analysis/oesummary/oesummary2005/oe2005-08.pdf
2. ***Lack of Protective Eyewear Results in Laser Eye Injuries*** (OES 2004-06)
   http://www.hss.doe.gov/SESA/Analysis/oesummary/oesummary2004/oe2004-06.pdf

## Lessons Learned

The following lessons learned are from the DOE Corporate Lessons Learned Database. The lessons learned in these reports primarily address conduct of operations failures that resulted in laser safety events.

1. ***Warning on Green Laser Pointers*** *(2010-SLAC-03)* - 12/06/2010
2. ***Electronic Personnel Safety System (PSS) Records Minimizes Opportunities for Mistakes and Can Improve Safety in Beam Enclosures*** *(JLab COE 268)* - 05/11/2009
3. ***Mislabeled Laser Protective Eyewear*** *(LL-2008-LLNL-08 (LLNL-AR-408676))* - 12/03/2008
4. ***Optiprexx LTD. Ruby Florescence System Mislabeled Laser*** *(2008-ANL-010)* - 10/23/2008
5. ***Don't Overlook Secondary Hazards*** *(LL-2008-LLNL-05 (LLNL-AR-406016))* - 08/18/2008
6. ***Ineffective Laser Lab Personnel Sweep (Near Miss)*** *(2007-TJNAF-0001)* - 06/15/2007
7. ***Final Take - Student Sustains Laser Eye Injury*** *(LANL CHEMLASER 2004-0011)* - 12/23/2004
8. ***Significant Operating Experience Report - DOE Complex Laser Injury Incidents*** *(2004-SR-WSRC-0048 )* - 10/13/2004
9. ***Student Sustains Laser Eye Injury*** *(LANL CHEMLASER 2004-0010 )* - 08/18/2004
10. ***Graduate Student Incurs Laser Injury to Eyes*** *(2004-CH-BNL-BES-001 )* - 03/26/2004
11. ***Failure to Wear Eye Protection Results in Laser Eye Burn*** *(1999-KO-SNL-0001)* - 04/09/1999
12. ***Failure to Wear Eye Protection Results in Laser Eye Burn*** *(1999-LA-LANL-ESH7-0005)* - 03/04/1999

## Additional Safety Information

**Standards**

ANSI Z136.1 – 2000, *American National Standard for Safe Use of Lasers*, governs laser safety in DOE and is invoked by 10 CFR Part 851. The Laser Safety Officer (LSO) is a contractor employee, not a DOE employee. The LSO has the responsibility and authority to monitor and enforce the control of laser hazards and effect the knowledgeable evaluation and control of laser hazards.

**Working Groups**

DOE has a very active EFCOG ESH Working Group Laser Safety Subgroup

- They are in the process of gathering data on the number/types of lasers at DOE facilities
- There have been no construction-related laser incidents
- While ANSI Z136.1 describes the role of the Standard Operating Procedures (SOP) as describing procedures used during normal operations, maintenance and service, a questionnaire on SOPs filled out by the labs indicates that in many laser facilities, the SOP is implemented as an overarching safety document that has a broader role - for example:
    - SOP is a contract between the laser users and the LSO, which describes the laser facility, its hazards and hazard controls (see for example Chapter 4 in Ken Barat's book "Laser Safety Management"). The controls described include engineering controls, administrative procedures and laser eyewear protection.
    - SOP is a technical specification document for the engineered laser safety system, which typically includes an access control system, interlocks, and safety shutters.
    - SOP is a reference document for laser personnel.
    - SOP is used as part of the initial training for laser personnel.




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