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SPECIAL OPERATIONS REPORT: LASER SAFETY

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 exposure. Visual disorientation from retinal damage may not be apparent to the individual until considerable thermal damage has occurred.

The laser eye exposures that occurred since 2001 have common root causes. All seven of the reported events are briefly summarized below.

Laser Exposure Events 2001–2005

October 26, 2001
Argonne National Laboratory – East

A graduate student and a visiting scientist with more than 15 years of laser experience were working with a Class 4 multiple laser system at full power when the scientist was struck in the right eye by specular reflection, resulting in a retinal burn and a loss of acuity in the eye. Neither researcher wore laser eye protection while repositioning a mirror element that investigators believe caused the beam to reflect off a stainless steel mounting post. Laser eyewear was not worn so that the researchers would see a small amount of visible light from the laser while aligning the mirror. This was a violation of standard operating procedures that specified the use of laser eye protection. Also, the potential for eye exposure while repositioning optical elements was not considered during the work planning process. *(ORPS Report CH-AA-ANLE-ANLECHM-2001-0001)*

> *Laser injuries to the eyes resulted from a lack of engineering controls and a failure to use personal protective equipment.*

October 4, 2002
Brookhaven National Laboratory

A beam line technician unknowingly stepped into the beam path and was struck twice in the eye while performing a beam angle measurement. No injury occurred because the beam power was below harmful levels. A post-doctoral researcher and a science associate had changed the configuration of the light path such that it was incompatible with the existing barrier and beam stop. The technician, who was not wearing laser eye protection, was unaware that the beam was now exposed and unprotected. The researchers' knowledge that the beam's power was weak resulted in their lack of concern for safety barriers, and they allowed work to proceed without communicating the altered configuration to co-workers. *(ORPS Report CH-BH-BNL-NSLS-2004-0001)*

March 14, 2003
Lawrence Berkeley National Laboratory

A graduate student suffered a non-permanent eye injury when struck by the specular reflection of a stray beam from a Class 3b pulsed laser. The student, who was not wearing laser eye protection at the time of the event, assumed an alignment task was complete and had removed his eyewear. Then, while manipulating a power meter in the path of the invisible infrared laser beam, he was struck by a reflection. The student failed to follow the safe work practices as stated in the Laser Safety Manual by not wearing laser eye protection and by not performing an adequate survey of the laser beam path. *(ORPS Report OAK--LBL-MSD-2003-0001)*

September 9, 2003
Brookhaven National Laboratory

An unsupervised graduate student received a retinal burn to both eyes when the beam of a Class 4 laser was reflected into his eyes by a mirror. The student was not wearing laser eye protection when he attempted to repeat an alignment procedure he had observed only once. The student did not fully understand the procedure and decided to use a procedure of his own that was inherently unsafe and was not authorized. In addition, the principal investigator had installed and operated the laser without registration and review by the Laser Safety Officer (LSO) and without required postings and documentation. *(ORPS Report CH-BH-BNL-BNL-2003-0019)*

July 14, 2004
Los Alamos National Laboratory

A student suffered permanent loss of central vision in her left eye when she looked directly into the path of a Class 4 laser beam while performing an unauthorized experiment with a principal investigator. Following the principal investigator's example, the student looked into the target chamber, directly in the beam's path. Both the student and principal investigator believed the laser was not producing laser light. The principal investigator routinely did not wear laser eye protection and trusted his ability to avoid the hazard. This failure to practice, model, and enforce safe behavior was transferred to the student and coworkers. The laser injury resulted from the lack of engineering controls and the lack of use of personal protective equipment. *(ORPS Report ALO-LA-LANL-CHEMLASER-2004-0001)*

September 17, 2004
Argonne National Laboratory – East

A principal investigator developed a temporary lesion in his left eye when he was struck by a Class 4 laser beam while adjusting an unguarded beam splitter without wearing laser eye protection. Because he neglected to cover the lateral ports, a stray beam bounced off the optic table and struck his unprotected left eye. A safety review of the experiment was not conducted by a laser subject matter expert; therefore, the hazard of the beam being directed off the optics table was not identified. *(ORPS Report CH-AA-ANLE-ANLEAPS-2004-0003)*

January 19, 2005
National Renewable Energy Laboratory - Golden Field Office

A researcher sustained a retinal burn to his right eye while operating a Class 4 Yttrium Aluminum Garnet laser. At the time of the incident, the researcher and his team leader were testing new sample instrumentation when a problem occurred with the instrumentation. While the team leader went to another part of the lab to obtain a different test sample, the researcher removed the neutral density filters to obtain a response from the test sample using full beam power. The researcher was not wearing his eye protection as he manipulated the test sample with a pair of stainless steel tweezers. At this point, he experienced seeing a flash of light off the test sample. (*ORPS Report GO--NREL-NREL-2005-0001)*

Integrated Safety Management

DOE needs to have confidence that effective laser safety programs are implemented across the Complex. One or all of the basic five functions of integrated safety management were not adequately implemented when eye exposures occurred. Specifically, there were failures to understand and identify hazards, failures to control hazards, inadequate training leading to insufficient competency to operate hazardous systems, and inadequate management oversight and performance feedback processes.

It is also apparent that too many researchers, both junior and senior, fail to comprehend the possible programmatic effects of noncompliance with safety requirements. They may assume that noncompliance will not result in an injury and will affect only themselves or their research. Many do not realize the serious implications for laboratory programs or the laboratory's reputation if an accident occurs. Recent laser accidents have caused shutdowns of entire divisions and even an entire laboratory.

Event Root Causes

There are four primary common causes for the laser accidents from 2001-2005. These causes are inadequate training, inadequate LSO conduct, the need for better internal oversight, and failure to wear Personal Protective Equipment (PPE).

Training

Training and an inadequate level of understanding of the hazards and controls were factors in most laser accidents analyzed. Also, there was an inadequate level of knowledge by those required to oversee laser operations and supervise laser users. Personnel were not familiar with or did not comply with the basic safety recommendations of ANSI Z136.1-2000, *Safe Use of Lasers*.

Weaknesses in training and a lack of compliance with accepted national standards were key contributors to accidents.

At the present time, laser safety training at many universities is inadequate and sometimes nonexistent. Often, safety is either not addressed or it falls within the responsibility of the researcher's mentoring duties. Thus, people coming from this environment may lack the safety culture that DOE expects in its work force.

Weaknesses in the training given to laser personnel contributed to many of the accidents. Deficiencies include depth of training, compliance with accepted national standards, training delivery methods, student training and mentoring, and training specific to the hazards at each facility. Strengthening training programs will be necessary to aid in minimizing future risk. Because many accidents have been related to aligning lasers, hands-on training must include aligning and adjusting laser equipment.

Laser Safety Officers

As laser technology grows, lasers become increasingly beneficial to a greater number of users for a wider variety of scientific applications. However, DOE's Laser Safety Officer (LSO) program has not kept pace. Most LSOs are part-time and do not hold the primary function or discipline as LSO.

A critical component of successful laser safety programs is the authority and role of the LSO. This position is vital for ensuring safe operation of lasers, especially for Class 3b and Class 4 lasers, which can potentially cause permanent physiological damage. A fully trained LSO is the competent expert to grant operational approval.

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The length of LSO training courses varies, typically from 3 days to 2 weeks. At some DOE facilities, LSO training has been gradually reduced from a live hands-on course to a 1- to 2-hour, computer-based training package. A review of the current DOE LSO training reveals a significant gap in what is taught versus what knowledge is required to successfully perform LSO duties.

LSO training is often generic in that it is one-time and "one size fits all." This training is often insufficient to prepare LSOs for the types of lasers used and potential hazards. Many LSOs have not had refresher training sufficient to keep pace with laser technology and changes in regulations, which hinders proper hazard evaluation.

In four of laser accidents that resulted in eye injuries, the LSO did not have the authority to grant operational authorization and had not adequately assessed the hazards and controls of the laser operation. Moreover, there was confusion over when it was appropriate to receive LSO review and approval. Additionally, confusion over authority between line management and the LSO was a significant cause.

ANSI Z136.1-2000, *Safe Use of Lasers*, describes in detail the roles and functions that an LSO is required to perform to ensure safe operation of lasers. A review of ANSI requirements versus those activities commonly performed by LSOs indicates that not all LSOs perform ANSI-required duties.

Currently, laser safety at each laboratory is independent, and no networking occurs between LSOs. Best practices must be rediscovered by each LSO. Hence, there is a need for an ongoing communication mechanism across the entire Department (e.g., a working group or coordinating committee). The mechanism would be a source for consistent application of laser safety practices across the DOE Complex. Current needs include a resource web page, problem-solving center, eyewear selection assistance, and Best Practices development. The mechanism could also develop training criteria recommendations for the DOE LSO, DOE Facility Representatives, and other DOE-specific laser applications.

Internal Oversight

Available information on management systems and practices indicates that infrequent or inadequate line management oversight of laser operations was a contributing factor to laser exposures. Periodic line management assessments of lasers, when they did occur, were inadequately documented or lacked sufficient rigor, formality, and follow-up. Also, LSO inspections or audits of these lasers had either not been conducted since the lasers were initially granted operational status or had been inspected infrequently. Some inspections or audits had not been conducted for several years. In addition, little documented evidence exists to show that line management followed up to ensure that deficiencies were corrected.

An effective self-assessment program and effective line management oversight should have discovered and resolved the accountability, programmatic, and procedural deficiencies that led to these injuries.

A common observation in most of these accident reports is that the hazards and their effective remediation were not fully understood by the researcher or the researcher was confident in his or her knowledge and experience and became complacent toward the hazards involved in the operation of Class 3b and Class 4 lasers. DOE also may have become complacent about the hazards encountered in the use of lasers.

> *Infrequent or inadequate line management oversight of laser operations was a contributing factor to laser exposures.*

All DOE institutions that operate lasers should establish: (1) clear roles, responsibilities, and authority for laser operations; (2) active management oversight of laser operations; (3) improvements in their approach to research using students; and (4) an effective enforcement policy.

Personal Protective Equipment

All six eye injuries would have been prevented if personnel had worn laser protective eyewear. Personnel either did not fully comprehend the need for the protective eyewear or thought that they had properly controlled the hazards in such a way that protective eyewear was not necessary.

If good engineering controls had been in place, no one would have been injured. Failure to implement adequate control measures puts the burden of safety on the protective eyewear.

> *Enforcement of the PPE requirement is an absolute necessity.*

Given the lack of ability to predict when hazardous beam energy is present, enforcement of the PPE requirement is an absolute necessity.

Laser Safety Performance Expectations

All DOE and contractor users of lasers are already required to comply with ANSI Standard Z136.1–2000. However, it is apparent that DOE does not comply and needs to renew and intensify its efforts with a special focus on the following areas.

Training

- DOE contractors that use lasers must implement laser training for the following personnel:
    - LSOs,
    - Users,
    - Students,
    - Supervisors of users (and other personnel responsible for oversight),
    - All laser personnel (refresher training), and
    - Incidental personnel (awareness training).
- Each DOE line organization overseeing contractors that use lasers must implement laser training for DOE Facility Representatives.
- In addition, the laser training program must meet the following criteria:
    - Comply with the current version of ANSI Z136.1, *Safe Use of Lasers*.
    - The depth of training is clearly tied to responsibilities and the degree of hazard.
    - The laboratory has documented the quality and depth of training for each type of laser personnel listed above. (For example, document the training source and course outline. The course will reflect the laser hazards at the laboratory.)
    - Hands-on training for the performance of alignment procedures should be administered by lab supervisors as part of a formalized and documented On-the-Job training process customized for each laser operation. Computer-based training alone is not acceptable.
    - Refresher training can be computer-based.
    - Training and mentoring programs for students have an emphasis on hazard analysis and control, as well as stopping or pausing work when conditions change or are uncertain.
    - Training includes guidance on aligning and adjusting laser equipment and is easily understood.
- Training for all personnel listed above should be upgraded and repeated if it does not meet these requirements. Grandfathering could be considered if the above criteria are demonstrably met.

Laser Safety Officers

- LSOs should have written authority through facility management to ensure that safe practices are implemented. At a minimum, LSOs must have operational authority consistent with ANSI Z136.1-2000.

- LSOs survey operations by inspection. Each laboratory should set a standard frequency for review and inspection of work areas and work practices.
- LSOs periodically observe new users, students, and visiting scientists to ensure that controls are in place and that PPE is worn.
- LSOs maintain a comprehensive, accurate inventory of lasers in use onsite.
- LSOs participate in laser accident investigations.

Internal Oversight

- Managers of all DOE facilities operating Class 3b or Class 4 lasers oversee laser operations to ensure that safety procedures are adequate and that work controls are in place and functioning. Therefore, management is responsible for:
    - establishing clear roles, responsibilities, and authority for laser operations,
    - demonstrating active oversight of all aspects of laser operations,
    - monitoring and evaluating mentors and principal investigators that oversee students, and
    - establishing and clearly explaining personal accountability, including a reprimand policy for employees that do not meet safety performance expectations.
- DOE site office managers that oversee operations that use lasers must verify within 90 days to the Department's Chief Safety Officer (EH-1), via their Program Secretarial Officers, that laser safety performance expectations are met.

Personal Protective Equipment

- Each laboratory must implement mandatory use of protective laser eyewear. Exceptions may be granted in writing by the LSO with proper hazard evaluation.