SUBJECT: Laser Safety Program

Purpose: The purpose of this Laser Safety Manual is to insure the safe use of lasers in research activities at the Colorado School of Mines (Mines or the School). This Laser Safety Manual outlines laser registration requirements, identifies hazards associated with using lasers, provides recommendations for laser usage, outlines training requirements and outlines medical monitoring requirements.

Authoritative Reference: American National Standard for Safe Use of Lasers (ANSI) Z136.1-2000.
Occupational Safety and Health Administration OSHA 29 CFR 1910.133 – Eye and Face Protection.
OSHA 29 CFR 1926.54 – Non-ionizing Radiation.

Laser Safety Manual Attachments:

Table 1 – ANSI Z136.1 Control Measures for the Four Laser Classes
Table 2 - Simplified Method for Selecting Laser Eye Protection for Intrabeam Viewing
Appendix A – Laser Registration Form
Appendix B – Laser System Standard Operating Procedures Template
Appendix C – Key Terms and Definitions

1. Assignment of Responsibilities

Faculty and Principal Investigators are responsible for the following:

- The immediate supervision of lasers in research and laboratory operations.
- Implement and enforce the safety recommendations and requirements outlined in this Laser Safety Manual.
- Complete written Standard Operating Procedures (SOP) for the use of class 3b and class 4 lasers under their supervision, and submit the SOP to the Environmental Health and Safety Department (EHS).
- Provide laser operators with specific safety and laser system operations training including review of the SOP developed for laser systems under their supervision.
- Classify and label all lasers under their supervision.
- Register all lasers under their supervision with EHS.
- Attend an EHS Laser Safety Training class.
- Participate in the medical monitoring program for use of class 3b and class 4 lasers.
- Notify EHS in case of injury following exposure to class 3 or class 4 lasers.

Laser operators are responsible for the following:

- Obtain laser specific training from the responsible Principal Investigator.
- Certify comprehension of the laser system operations and safety requirements by signing the laser system SOP signature page.
- Inform Faculty, Principal Investigators, and EHS of any safety or exposure incident or any variation or modification to the laser operation and the SOP.
- Attend the EHS Laser Safety Training class.
- Participate in the medical monitoring program for users of class 3b or class 4 lasers.
- Follow established laser system SOP and safety policies during laser operation.

Prior authorization is required from the Principal Investigator for all student laser operators to work independently with class 3b and class 4 laser systems. Consideration of the operator's technical training, applicable experience, and satisfaction of the laser operator requirements listed above should be included with the Principal Investigator's authorization for a laser operator to work independently. Authorization to operate a laser independently must be documented on the signature page of the laser system SOP.

The Environmental Health and Safety Department is responsible for the following:

- Conduct inspections of laboratory facilities to ensure standard operating procedures and safety procedures are implemented.
- Assist Faculty and Principal Investigators in evaluating and controlling laser hazards.
- Revise the campus Laser Safety Procedures.
- Maintain a database of registered lasers.
- Review prepared SOP for laser systems used on campus.
- Maintain records of laser safety training.
- Conduct and assist with laser safety training for academic departments.
- Participate in accident investigation involving lasers.
- Coordinate and maintain the medical monitoring program.

2. Personnel Training and Qualifications

All staff and students who operate class 3 or class 4 lasers are required to attend a Laser Safety Training class presented by the EHS department. The Laser Safety Training will address:

- The biological effects of lasers.
- The physical principals of lasers.
- Laser classifications.
- Controls for laser laboratories and laser areas.
- Medical monitoring.
- Safety.
- Protective equipment and selection.
- Non-beam hazards such as electrical, fire, cryogenics and laser produced air contaminants.

- Emergency response.
- Exposure incident reports.

3. Medical Monitoring Program

Laser operators, who routinely work in laser areas where class 3b or class 4 lasers are used, should have a baseline eye examination. The examination will include an ocular history, a macular function test using an Amsler Grid examination and a visual acuity test. Costs of this examination will be paid by the EHS Department.

- Eye examinations should be completed prior to Graduate Student and Principal Investigator's initial work with lasers.
- To schedule an eye examination, contact the EHS Department by calling 303-273-3869 or 303-273-3316 and request a laser eye examination.
- An eye examination is recommended upon termination of work as a laser operator.
- Eye examinations are required immediately following any accidental exposure or injury as a result of working with a laser.
- Incidental contact or association with laser operations, where exposure to laser radiation sufficient to damage the eyes or skin is unlikely, does not necessitate participation in the medical monitoring program.
- Periodic exams following the initial exam are not required.

4. Laser Exposure Incidents

In the event of an exposure or suspected exposure, EHS must be notified immediately. The laser operator, Principal Investigator or a Faculty member associated with the laser operation must ensure EHS receives notification. The operator who received the exposure should immediately follow these procedures.

- Shut down the laser operation. Emergency shut down procedures must be identified in the laser system SOP.
- Seek immediate medical attention.
- Notify the Principal Investigator, an academic Faculty member or EHS.

EHS will conduct an investigation into the incident and a report will be completed.

5. Laser Hazard Analysis

The selection of controls, safety equipment and the development of standard operating procedures requires an identification and evaluation of individual laser radiation hazards. The hazards associated with laser radiation include:

- Eye Injury – Acute, short term, exposure to lasers of certain wavelengths and power have the potential to cause photokeratitis and more permanent damage by burning the cornea and or retina. Chronic, long term, exposures may lead to opacity damage (Cataracts) to the lens/cornea or damage to the retina.

- Skin – Acute exposures to laser radiation of certain wavelengths and power may cause erythema, reddening of the skin, and skin burns. Chronic exposure to ultraviolet wavelengths has been linked to the development of skin cancer.
- Non-Beam Hazards – Non-beam hazards must also be considered and controls for these hazards must be identified on the laser SOP. Non-beam laser hazards are included in Section 14 of this Laser Safety Manual.

EHS and the Principal Investigator will assemble laser information for each laser system and conduct a nominal hazard zone analysis when required. A nominal hazard zone analysis identifies laser areas where laser radiation is of sufficient power to cause injury to skin and eyes.

6. Laser Classifications

Lasers are generally classified and controlled according to their classification. The classification is based on the physical characteristics of the laser and the laser's potential for causing injury or accidents. Physical characteristics include power, wavelength and duration of exposure or pulse. Potential for causing injury or accident include immediate injury to the eyes or skin or likelihood for starting a fire either directly or from reflective surfaces.

All lasers, manufactured after August 1, 1976, have been classified by the manufacturer and identified by a label identifying the laser classification. Lasers are classified using the following criteria.

- Class 1 – Low-power lasers and laser systems that cannot emit radiation levels greater than the Maximum Permissible Exposure (MPE). Class 1 lasers are incapable of causing eye injury and are exempt from control measures. Example: laser printer.
- Class 2 – Visible low power lasers or laser systems that are incapable of causing eye damage unless viewed for extended periods of time. Protection is provided by the normal human aversion blink response. Example: laser pointers.
- Class 3a – Lasers that do not produce injury when viewed under normal conditions for short periods of time. Injury could result from the use of collecting optics or from chronic viewing. Example: HeNe lasers above 1 milliwatt (mW) but less than 5 mW of radiant power.
- Class 3b – Lasers that produce eye injury when viewed directly or from specular reflection. These may be visible or invisible beams. The power output ranges from 5 to 500 mW for continuous wave lasers or the lower of 10 joules per square centimeter (J/cm^2) or the diffuse reflective limit for pulsed lasers.
- Class 4 – High power lasers capable of causing severe eye damage with short duration exposures to the beam directly or through a specularly reflected or diffusely reflected beam. Class 4 lasers are also capable of causing damage and burns to the skin as well as igniting flammable or combustible materials.

It is the responsibility of the Principal Investigator to ensure proper labels that identify the laser classification are present on all lasers under their supervision. The Principal

Investigator must also ensure any laser produced or fabricated at Mines is properly classified, labeled and registered with EHS prior to its use. Principal Investigators may contact EHS for assistance with classifying and labeling laser systems.

7. Safety Recommendations - All Laser Classifications

Eye Protection – Laser protective eyewear only offers protection against specific wavelengths. One type of laser protective eyewear may not provide protection when there is more than one laser or more than one wavelength emitted. Principal Investigators must provide appropriate eye protection for lasers under their supervision.

The EHS Department will assist with the selection of the most appropriate eye protection. The book Guide for the Selection of Laser Eye Protection, published by the Laser Institute of America should be referenced to aid with the selection of laser protective eyewear. A copy of this book is available through EHS. The guide Simplified Method for Selecting Laser Eye Protection for Intrabeam Viewing is available online at http://kentek-laser.com/helpers/selecteyewear.htm. A copy of this selection guide is included with this Manual in Appendi**x** D. Specific requirements for eye protection when class 3b and class 4 laser systems are in use are outlined in Section 10 of this Laser Safety Manual.

Beam Controls - Whenever possible the following safety guidelines should be followed to minimize potential exposures to the eyes or skin.

- Confine or enclose the beam.
- Use non-reflective beam stops and enclosures.
- Do not align laser optics by direct viewing.
- Always use the lowest power possible to complete beam alignment operations.
- Always use the minimum power level to complete the required application.
- Keep optical benches clear of reflective materials.
- Confine the beam to the optical bench. Use barriers or other enclosures at the sides of optical benches.
- Use non-reflective tools.
- Avoid wearing reflective jewelry when working with lasers.

Required Controls and Safety Measures for Class 1, Class 2 and Class 3a Lasers

Labels - Ensure a manufacturer's label which identifies the laser classification and applicable warnings is attached to the laser. See Section 6 of this Laser Safety Manual for additional information on laser classification and labeling requirements.

Class 3a Operational Controls – Operators of class 3a lasers must follow the operational procedures for direct viewing, alignment procedures and the use of optical viewing aids described in Section 10 of this Laser Safety Manual.

Class 3a Training – Operators of class 3a lasers must attend the EHS Laser Safety Training class.

Specific recommendations and required administrative and operational controls for each laser classification operated at Mines are identified in Table 1 located on Page 14 of this Laser Safety Manual

8. Administrative Controls for Class 3b and Class 4 Lasers

Laser System Registration – Principal Investigators must register all class 3b and class 4 lasers under their supervision with EHS. The registration form is available with this Laser Safety Manual in Appendix A. An electronic copy is available with calling EHS.

Standard Operating Procedures – All Principal Investigators are required to prepare a written SOP for each class 3b and class 4 laser or laser system under their supervision at the School. A copy of the SOP must be submitted to EHS. The SOP must also be posted in the laboratory where the laser is operated and made available to all laser operators.

All SOPs must identify the specific laser and address laser start up, operating procedures, alignment, area access, maintenance, shut down, beam controls, warning systems and related safety procedures. All laser operators must sign the signature page on the SOP to certify their review and understanding of the proper operation of the laser system. Principal Investigators must approve student laser operators for independent work with a laser system on the SOP.

Lasers used in research applications often generate the need for unique operating procedures. These operating procedures often increase the potential for exposure. A written SOP must address any unique situations where the laser will be operated in a manner that could increase the potential for exposure. Required safety procedures to prevent exposure to laser radiation must be outlined. Examples of these unique situations include:

- Operations which require the use of laser protective eyewear, shields, enclosures and access control that fall outside normal operations.
- Use of two or more class 3b or class 4 lasers in the same laboratory by separate operators without permanent barriers.
- Use of an interlock bypass.
- Situations where a class 3b or class 4 lasers are operated by visiting or contract personnel at the School.
- Research operations that require the use of School owned class 3b or class 4 lasers off the Mines campus.
- Operation of a laser laboratory that is not equipped with controls identified in this Laser Safety Manual.
- Operations that bypass established engineering controls.
- The unattended operations of class 3b or class 4 laser systems.
- Laser system modifications.
- Control of non-beam hazards such as electrical equipment, toxic or flammable materials.

A template for the preparation of a laser system SOP is included with this Laser Safety Manual in Appendix B. An electronic copy is available by calling EHS.

Labels – All class 3b and class 4 lasers must be labeled with the manufacturers label identifying the laser classification and applicable warnings. The circuit breaker that controls electrical power to the laser must be clearly identified. Principal Investigators are responsible for the inspection and replacement of missing labels. Contact EHS if assistance with replacement labels is required.

Warning Signs – Each entrance to a laser laboratory and laser area where a class 3b or class 4 laser is operated must be posted with warning signs as specified by ANSI Z136.1-2000 Figure 1b or Figure 1c. EHS also recommends warning signs on the entry door to class 3a laser laboratories. Principal Investigators should contact EHS for assistance with the selection of appropriate warning signs.

Operation, Service, and Maintenance Log - An operations log must be maintained for each class 3b and class 4 laser used on the Mines campus. This log should show periods of laser operation in the laboratory as well as periods of service and maintenance. The type of service or maintenance performed should be included. Tests on safety equipment such as Interlocks, warning lights, and the emergency power shut off must also be documented.

Access Control - During class 3b and class 4 laser operations, laser laboratories must be operated to limit access. The activation of warning lights and warning signs on the laboratory access door is an example of a system to control access during times the laser is energized.

Access to the laser control area may be granted to authorized and trained personnel only at the discretion of the Principal Investigator or laser operator.

Training – All operators of class 3b and class 4 lasers must attend a Laser Safety Training class presented by the EHS Department. Training requirements are outlined in Section 2 of this Laser Safety Manual.

Authorized Personnel and Laser Area Visitors – Authorization to enter an operational laser control area is provided by the Principal Investigator. The Principal Investigator must identify all laser system hazards, the warning system, emergency procedures and the appropriate laser protective eyewear. This introduction to the laser system does not provide authorization to operate a class 3b or class 4 laser system.

Laser Maintenance and Service Personnel – Only trained personnel are permitted to perform maintenance on lasers and laser systems. All equipment including interlocks, alarms, warning lights, and relief devices will be maintained, calibrated, and tested on a regular basis in accordance with the manufacturers recommended service intervals.

See the Operations, Service and Maintenance Log portion of this Section for additional information.

For maintenance completed by Mines personnel, the name and qualifications of the person maintaining the laser and laser system must be included in the laser SOP.

Medical Monitoring – Prior to working with class 3b and class 4 lasers, laser operators should complete an eye exam as part of the School's medical monitoring program. The medical monitoring program is described in Section 3 of this Laser Safety Manual.

9. Engineering Controls for Class 3b and Class 4 Lasers

Protective Housings – All class 3b and class 4 lasers and laser systems need to be enclosed in a protective housing during normal operations. Protective housings on class 3b and class 4 lasers must be equipped with a safety interlock to prevent laser operation when the housing is removed. Activities that require the operation of the laser without the protective housing requires additional administrative and engineering controls including:

- Eye Protection.
- Barriers, shrouds, beam stops and other engineering controls to prevent exposure to the beam.
- Written procedures outlined in the laser system SOP.
- Evaluation of the procedures by EHS.

Protective housings which allow walk-in access to a class 3b or class 4 laser control area must be equipped with a warning system and an interlock with the laser power supply to prevent laser activation and potential exposure to laser radiation above the MPE.

Removal of service access panels must be managed in the same manner as protective housings. The service panel must be interlocked to prevent operation of the laser when the panel is removed. Activities that bypass an interlock on the access panel requires eye protection, barriers, shrouds, a written SOP and evaluation of the operating procedures by EHS.

Key Control or Access Codes – Class 4 lasers must be equipped with a master switch and key or uses an access code that prevents unauthorized use of the laser. Keys and access codes should not be left with the laser when it is not in use. EHS recommends the use of key controls or access codes for class 3b lasers as well.

Activation Warning Systems – All class 4 lasers must use a system which includes an audible sound such as a bell or a verbal countdown to warn of imminent laser activation or startup. Visual warnings such as a flashing light during laser activation and operation must also be used. EHS recommends the use of similar activation warning systems for class 3b lasers.

Safety Interlocks – Access doors to a laser laboratory or enclosures around a laser area where class 3b or class 4 lasers are operated must be equipped with safety interlocks to prevent laser operation when the safety interlock circuit is broken. Interlocks must be tested quarterly and a written record of the interlock test must be documented in the laser system log book.

Protective enclosures surrounding class 3b and class 4 laser control areas and high voltage electrical sources must also be equipped with interlocks. The interlock design must ensure the system cannot be reenergized when protective housing or enclosures are removed.

In situations where interlocks are not feasible, the Principal Investigator may consider the use of warning lights, alarms or voice warnings to notify personnel not to enter laboratories and laser areas where class 3b or class 4 lasers are in use. These procedures must be included in the SOP and approved by the EHS Department prior to laser operations.

Beam Stops and Attenuators - All class 4 lasers must be equipped with a permanent beam stop or beam attenuator. A beam stop or attenuator can be used to reduce laser radiation levels below the MPE. Situations where a beam stop or beam attenuator must be used include instances when the laser is not operated at full power, during service events, when the laser is in standby mode, or during a required warm up period. For lasers that do not require a warm up period, the power switch may be substituted for a beam stop or attenuator. EHS recommends the use of a stop or beam attenuator with all class 3b lasers.

Laboratory Equipment - Windows and doors must be covered to prevent injury due to a reflected beam. Diffuse reflective materials should be provided for use in laser laboratories. All mirrors, prisms and beam stops in the path of the beam must be securely fastened to the optical table. The laser unit must also be securely fastened. Class 3b and class 4 infrared lasers with wavelengths greater than 710 nanometers must be terminated with fire resistant materials.

Reflection Controls – As listed under Laboratory Equipment in this Section, only materials that diffusely reflect laser radiation should be used. To minimize personnel exposure, specularly reflecting surfaces that are needed for beam path control must be enclosed or shielded. Any reflective materials that are not needed must be moved from the laser operating area.

Beam Enclosures – The entire beam path as well as the beam termination point of class 3b and class 4 lasers should be fully surrounded by an enclosure and equipped with interlocks that prevent the operation of the laser system unless the enclosure is properly secured. In situations where a class 3b or class 4 laser is open or not enclosed, the Principal Investigator and EHS will evaluate the nominal hazard zone. The nominal hazard zone analysis will be used to delineate a laser control area. This

analysis will be used to identify appropriate controls to prevent injury from laser radiation. These controls must be included in the written SOP for the laser system.

Invisible Beam Controls – Ultraviolet and infrared lasers that emit invisible beams are subject to the following additional controls.

- Visual or audible warning devices must be installed at the entryway to the laser laboratory and around a laser control area where personnel may be exposed to an invisible beam. These warning devices must be clearly identified and visible from all areas of the laser laboratory where the potential for exposure exists.
- Shielding must be used to attenuate the ultraviolet radiation to levels below the MPE.
- The use of intense ultraviolet radiation may cause the generation of hazardous byproduct materials. Controls for these hazardous byproduct materials must be considered and outlined under non-beam hazards in the laser system's SOP.
- Infrared beam enclosures and backstops must be fabricated of infrared absorbing materials. In situations where class 4 infrared lasers are used, the materials must also be fire resistant.

10. Operational Procedures for Class 3 and Class 4 Lasers

Direct Viewing Procedures– Laser operators and authorized laboratory personnel must never look directly into any laser beam unless this practice is specifically outlined as a safe procedure in the written SOP for the laser system. In cases where it is necessary to directly view a beam from class 3 or class 4 lasers, special provisions such as the use of filters and beam attenuators are mandatory. These special provisions must lower the exposure to laser radiation to below the determined MPE while viewing the beam. The procedures for safely viewing the class 3b and class 4 lasers must be outlined in the laser systems standard operating procedures.

Alignment Procedures– Alignment of class 2, class 3 and class 4 lasers and optical systems must be performed in a manner that does not allow eye exposure to the beam or specular reflection above the MPE. Whenever possible, class 1 or class 2 lasers should be used to align class 3 or class 4 lasers. Temporary beam attenuators placed over the beam aperture can reduce the laser radiation level below the MPE. SOPs for class 3b and class 4 lasers must include alignment procedures and controls.

Optical Viewing Aids – Optical systems such as cameras, telescopes, lenses, microscopes, etc. may potentially increase the exposure hazards to the eyes. Collecting optics intended for viewing a laser must incorporate appropriate controls such as filters or attenuators to maintain laser radiation levels transmitted through the optical systems below the MPE. The safe use of collecting optics for class 3b and class 4 lasers must be described on the laser SOP.

Eye Protection - Laser protective eyewear must be worn whenever radiation form a class 3b or class 4 laser has the potential to exceed the MPE. Irrelevant to the laser

MPE, laser operators should always wear laser protective eyewear when lasers are in use.

Laser protective eyewear provides protection over a narrow range of the laser spectrum. Protective eyewear may provide protection at one wavelength but provide no protection at a different wavelength.

For dual wavelength lasers, appropriate laser eye protection must be evaluated by the Principal Investigator and EHS. Consult laser protective eyewear manufacturer's product information and consult EHS for assistance selecting appropriate laser protective eyewear.

Eyewear is subject to damage and deterioration over time. Everyone involved with a laser laboratory must take the time to thoroughly inspect the laser protective eyewear. The inspection should ensure side shields are incorporated into the laser eyewear to prevent accidental eye exposure from specular reflection of the beam. Principal Investigators are responsible for replacing damaged eyewear and for taking damaged eyewear out of service.

Appropriate eyewear must be identified in the laser systems SOP. An adequate supply of laser protective eyewear must be available for laser operators, authorized researchers and visitors to the laser laboratory.

11. Unattended Equipment

Unattended lasers must be secured to prevent unauthorized use or activation of the laser system. Operators must de-energize power supplies and remove the keys from the power switch or use all other means to prevent unauthorized use of a laser system.

The operation of an unattended laser is permitted only when the procedures are included with the laser system SOP and approved by EHS.

12. Temporary Laser Facilities

For situations such as service adjustments, maintenance, or training, it may be necessary to establish a temporary laser facility. Temporary laser facilities may require the removal or bypass of protective equipment and safety interlocks. Since a temporary laser facility will not have the standard safety features installed or active during these situations, the SOP for the laser system must describe provisions for protecting laser operators and laboratory personnel. These provisions must include restricting access, use of proper laser protective eyewear and enclosure of optical path to prevent exposure to the beam above the MPE.

Temporary facilities for training purposes often are scheduled long after the preparation of the SOP. For unforeseen situations where a laser will be used for training in a

temporary setting, the Principal Investigator must notify EHS of the establishment of a temporary laser facility.

13. Converting to a Class 1 Enclosed Laser

Any laser or laser system can be converted to a class 1 laser by including all of the following controls in the laser system design.

Protective Housing

- Use a protective housing to enclose the laser system to prevent the release of laser radiation above the MPE.
- Ensure the protective housing prevents access to the laser system and beam during operation using interlocks.
- Laser operators who require access to an enclosure to adjust optics or perform maintenance must be familiar with the potential hazards associated with the beam and the use of controls, protective eyewear, and enclosures for performing these tasks.
- The types of enclosures and controls must be identified in the laser system SOP.

Safety Interlocks

- Use interlocks where the protective enclosure can be opened, removed or displaced.
- The interlocks must de-energize the laser to prevent exposure to laser radiation above the MPE.
- Service adjustments or maintenance work must not render the interlocks inoperable.
- Service adjustments or maintenance work must be controlled so exposures outside an enclosure can not exceed the MPE.

Additional Requirements

- The protective enclosure and the laser system must be designed and fabricated so that if an enclosure failure occurs, the enclosure system will continue to meet the requirements for an enclosed laser system.
- Modifications to commercial laser systems must be evaluated by the Principal Investigator supervising the laser. These modifications as well as revised procedures and controls for the operation of the modified laser must be identified in the laser SOP.
- Use viewing windows containing suitable filtering material that will attenuate laser radiation to below the MPE during laser operations.
- Label the enclosure with “Caution-Enclosed Laser” in readily visible locations on the laser enclosure.
- Attach a label that identifies the laser classification directly to the laser so the classification is identified in the absence of the enclosure. The use of these controls will enclose the laser and prevent contact or exposure to laser radiation while permitting unrestricted access into a laser laboratory.

14. Associated Hazards

In addition to laser beam hazards and exposures to laser radiation, chemical and physical hazards related to laser operation must be evaluated and controlled. In situations where non-beam hazards exist in a laser laboratory, the Principal Investigator must identify the hazards and outline control mechanisms in the laser system SOP.

Electrical Equipment – Laser operators must be aware of potential electric shock or fire hazards associated with the electrical power sources. Any installation, operation, maintenance, or modification of these electrical systems must be inspected by the Plant Facilities Electric Shop.

Ionizing Radiation – A laser operation may involve ionizing radiation from the presence of radioactive materials or the use of electrical power above 15 kilovolts. The use of radioactive materials must be included in the laser system SOP. Electrical power usage information is required on the EHS laser registration form.

Non-ionizing Radiation – Microwave and radio frequency fields may be generated by laser systems or support equipment.

Lighting – If lights are turned off or dimmed during laser operations, control switches must be installed at convenient locations or radio controlled lighting controls may be used. Luminescent strips should be used to identify table and equipment corners, control switch locations and aisles. In situations where natural lighting is not sufficient for safe egress, emergency lighting must be used.

Hazardous Materials – Use and store only those hazardous materials that are needed for the laser operation. Do not allow laser beams or strong reflections to contact combustible or flammable liquids or gasses. A material safety data sheet (MSDS) for each hazardous material used in the laser laboratory must be posted in the MSDS binder in the laboratory. Laser operators must be familiar with the information contained in the MSDS including proper storage, flammable properties and potential health effects before working with the hazardous material. MSDSs are available through EHS.

Dyes – Dye lasers typically use a lasing medium composed of a fluorescent organic dye dissolved in an organic solvent. Toxicity and flammability of these dyes vary greatly depending on both the type of dye and the solvent. Laser operators and Principal Investigators are responsible for ensuring an MSDS for all dyes and solvents is available in the laboratory MSDS binder. Mixing of laser dyes should occur inside a laboratory fume hood. Appropriate gloves and eye protection must be worn while preparing these dye solutions. Call EHS for assistance with selecting the most appropriate protective equipment. Laser operators should pressure test all laser dye components before using a dye solution.

Laser Generated Air Contaminants – Air contaminants may be produced by the interaction of the laser beam with target materials. Fumes and aerosols may be

produced when a laser beam burns a metal or organic material. Adequate local exhaust ventilation needs to be provided in the laser target zone to collect and remove airborne contaminants. EHS can assist Principal Investigators with the evaluation and design of a local exhaust ventilation system to control air contaminants.

Cryogenic Liquids – Some laser systems require the use of cryogenic liquids such as liquid nitrogen during laser operations. Skin or eye contact with cryogenic liquids can cause frost bite resulting in tissue damage. Cryogenic liquids can also displace oxygen in a room if the space is small or poorly ventilated. Appropriate protective equipment should be worn when operations require potential contact with cryogenic liquids. Laser operators should use appropriate dewars to move cryogenic liquids to the laser laboratory. Operators must also ensure the cryogenic liquid is used in a well ventilated area.

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TABLE 1 Control Measures for the Four Laser Classifications
Reproduced from ANSI Z136.1 – 2000

Control Measures and ANSI Standard Citation	*Laser Classification*				
Recommended Engineering Controls	**Class 1**	**Class 2**	**Class 3a**	**Class 3b**	**Class 4**
Protective Housing (4.3.1)	**X**	**X**	**X**	**X**	**X**
Without Protective Housing (4.3.1.1)	**Establish Alternate Procedures And Document In Laser System SOP**				
Interlocks on Protective Housing (4.3.2)	⩛	⩛	⩛	**X**	**X**
Service Access Panel (4.3.3)	⩛	⩛	⩛	**X**	**X**
Key Control (4.3.4)	**–**	**–**	**–**	●	**X**
Viewing Portals (4.3.5.1)	**–**	**MPE**	**MPE**	**MPE**	**MPE**
Collecting Optics (4.3.5.2)	**MPE**	**MPE**	**MPE**	**MPE**	**MPE**
Totally Open Beam Path (4.3.6.1)	**–**	**–**	**–**	**X-NHZ**	**X-NHZ**
Limited Open Beam Path (4.3.6.2)	**–**	**–**	**–**	**X-NHZ**	**X-NHZ**
Enclosed Beam Path (4.3.6.3)	**No Requirement If 4.3.1 And 4.3.2 Are Followed**				
Remote Interlock Connector (4.3.7)	**–**	**–**	**–**	●	**X**
Beam Stop or Attenuator (4.3.8)	**–**	**–**	**–**	●	**X**
Activation Warning Systems (4.3.9.4)	**–**	**–**	**–**	●	**X**
Emission Delay	**–**	**–**	**–**	**–**	**X**
Indoor Laser Controlled Area (4.3.10)	**–**	**–**	**–**	**X-NHZ**	**X-NHZ**
Class 3b Laser Controlled (4.3.10.1)	**–**	**–**	**–**	**X**	**–**
Class 4 Laser Controlled (4.3.10.2)	**–**	**–**	**–**	**–**	**Required**
Outdoors Control (4.3.11)	**–**	**–**	**–**	**X-NHZ**	**X-NHZ**
Laser in Navigable Airspace (4.3.11.2)	**–**	**–**	●	●	●
Temporary Laser Controlled Area (4.3.12)	⩛ **- MPE**	⩛ **- MPE**	⩛ **- MPE**	**–**	**–**
Remote Firing and Monitoring (4.3.13)	**–**	**–**	**–**	**–**	●
Labels (4.3.14 and 4.7)	**X**	**X**	**X**	**X**	**X**
Area Postings (4.3.9)	**–**	**–**	●	**X-NHZ**	**X-NHZ**

X = Required
● = Should
– = No Requirement
⩛ = Shall / Must If Enclosed Class 3b or Class 4 Laser
MPE = Required if Maximum Permissible Exposure Is Exceeded
NHZ = Nominal Hazard Zone Analysis Required
***** = Applicable Only To Ultraviolet and Infrared Lasers (4.5.1.2)

Colorado School of Mines
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TABLE 1 (Continued) Control Measures for the Four Laser Classifications
Reproduced from ANSI Z136.1 – 2000

Control Measures and ANSI Standard Citation	*Laser Classification*				
Administrative And Procedural Controls	**Class 1**	**Class 2**	**Class 3a**	**Class 3b**	**Class 4**
Laser Registration (Mines Policy)				X	X
Standard Operating Procedures (4.4.1)	–	–	–	X	X
Output Emission Limitations (4.4.2)	–	–	Require Evaluation & Control		
Education And Training (4.4.3)	–	●	●	X	X
Authorized Personnel (4.4.4)	–	–	–	X	X
Alignment Procedures (4.4.5)	–	X	X	X	X
Protective Equipment (4.6)	–	–	–	●	X
Spectator (4.4.6)	–	–	–	●	X
Service Personnel (4.4.7)	⩛ - MPE	⩛ - MPE	⩛ - MPE	X	X
General Public Demonstration (4.5.1)	MPE *	X	X	X	X
Laser Optical Fiber System (4.5.2)	MPE	MPE	MPE	X	X
Laser Robotic Installations (4.5.3)	–	–	–	X - NHZ	X - NHZ
Eye Protection (4.6.2)	–	–	–	● - MPE	X - MPE
Protective Windows (4.6.3)	–	–	–	X - NHZ	X - NHZ
Protective Barriers And Curtains (4.6.4)	–	–	–	●	●
Skin Protection (4.6.6)	–	–	–	X - MPE	X - MPE
Other Protective Equipment (4.6.7)	Require Evaluation & Control And Use As Outlined In The SOP				
Warning Signs And Labels (4.7) (Design Requirements)	–	●	●	X - NHZ	X - NHZ
Service And Repairs (4.4.7)	Require Evaluation & Control. Develop SOP				
Modifications & Laser Systems (4.1.2)	Require Evaluation & Control. Develop SOP				

X = Required
● = Should
– = No Requirement
⩛ = Shall / Must If Enclosed Class 3b or Class 4 Laser
MPE = Required if Maximum Permissible Exposure Is Exceeded
NHZ = Nominal Hazard Zone Analysis Required
***** = Applicable Only To Ultraviolet and Infrared Lasers (4.5.1.2)

TABLE 2 **-** Simplified Method for Selecting Laser Eye Protection for Interbeam Viewing for Wavelengths Between 100-1400 nanometers**

Q-Switched Lasers (10^{-9} - 10^{-2}) Seconds		Non-Q-Switched Lasers		Continuous Wave Lasers Momentary (0.25 – 10) Seconds)		Continuous Wave Lasers Momentary (Less than 1 Hour)		Attenuation	
Maximum Energy Output ($J•cm^2$)	Maximum Beam Radiant Exposure (J)	Maximum Energy Output ($J•cm^2$)	Maximum Beam Radiant Exposure (J)	Maximum Power Output (W)	Maximum Beam Irradiance ($W• cm^2$)	Maximum Power Output (W)	Maximum Beam Irradiance ($W• cm^2$)	Attenuation Factor	OD
10	20	100	200	10^5 *	$2x10^5$ *	100 *	200	100,000,000	8
1	2	10	20	10^4 *	$2x10^4$ *	10 *	20	10,000,000	7
10^{-1}	$2x10^{-1}$	1	2	10^3 *	$2x10^3$ *	1	2	1,000,000	6
10^{-2}	$2x10^{-2}$	10^{-1}	$2x10^{-1}$	100 *	200 *	10^{-1}	$2x10^{-1}$	100,000	5
10^{-3}	$2x10^{-3}$	10^{-2}	$2x10^{-2}$	10	20	10^{-2}	$2x10^{-2}$	10,000	4
10^{-4}	$2x10^{-4}$	10^{-3}	$2x10^{-3}$	1	2	10^{-3}	$2x10^{-3}$	1,000	3
10^{-5}	$2x10^{-5}$	10^{-4}	$2x10^{-4}$	10^{-1}	$2x10^{-1}$	10^{-4}	$2x10^{-4}$	100	2
10^{-6}	$2x10^{-6}$	10^{-5}	$2x10^{-5}$	10^{-2}	$2x10^{-2}$	10^{-5}	$2x10^{-5}$	10	1

* Not recommended as a control procedure at these levels. These levels of power output could damage or destroy the attenuating materials in the protection. The skin also needs protection at these levels.

** Use of this table may result in optical densities (OD) greater than necessary. See ANSI Z136.1-2000, Section 4.6.2 for other wavelengths.

Appendix A

Laser System Registration Form

Colorado School of Mines - Laser Registration Form

All class 3b and class 4 lasers must be registered with the Environmental Health and Safety Department (EHS). Please forward the completed registration form to EHS.

1. General Information

Principal Investigator:_____

Academic Department:_____

Office Location:_____ Phone Extension:_____ E-

Mail Address:_____

2. Laser System Description

Location of Laser (lab number and building):_____

Manufacturer Name:_____ Model Number:_____

Serial Number:_____ Laser Classification:_____

Laser Type (Nd-YAG, CO_2, etc.:_____

Use of Laser System:____R&D ____Analysis ____Demonstration ____Other*
(Check all that apply)

Other_____

3. Optical Characteristics

Wavelength(s) or Range (nm):____

Beam Diameter (mm):____

Beam Divergence (mrad):_____

Nominal Hazard Zone (NHZ) If Provided by the Manufacturer:_____

4. Operating Mode

Continuous Wave:____ Maximum Average Power (watts):_____

Exposure Distance (meters)_____

Pulsed:____ Joules/pulse:_____

Pulse Duration (Sec):_____ Repetition Rate:_____

Q-Switched:____ Pulse Width:_____

Has the laser been modified from its original design/configuration? (Yes or No)_____

If Yes – Describe Modifications:_____

_____

_____

Safety Precautions – Please verify the following controls are in place.

Yes	No	Please verify the use of the following controls.
		Access / Postings
		Posted Entrance
		Laboratory Security (key card or limited laboratory access)
		Established Control Area
		Warning Signs
		Administrative Controls
		Written Standard Operating Procedures
		Written Alignment Procedures
		Personnel Trained In Standard Operating Procedures
		Emergency Contacts Posted
		Personnel Authorization
		Laser Classification Label
		Laser Hazard Label
		Engineering Controls
		Enclosed Beam
		Protective Housing
		Protective Housing Interlock
		Service Panel Interlock
		Key / Access Pad Control
		Beam Stop / Attenuator
		Activation Warning Systems
		Window / Doorway Covered
		Reflective Materials Removed
		Personal Protective Equipment
		Laser Protective Eyewear
		Skin Protection Procedures
		Safe Practices
		Laser and Optics Secured to Table or Work Surface
		Beam Intensity Reduced for Alignment
		Laser Located Below Eye Level
		Use of Optical Viewing Aids With Procedures in SOP
		Non-Beam Hazards
		Laser Dyes in Use
		Compressed Gases in Use
		Cryogenic Material in Use
		Local Exhaust Ventilation in Use
		Fire Hazards Evaluated
		Electrical Hazards Evaluated

Upon completion of this form please return to:
Environmental Health and Safety Department
Chauvenet Hall Room 195
Fax (303) 384-2081

Appendix B

Laser System Standard Operating Procedures Template

Laser System Standard Operating Procedures for Class 3b and Class 4 Lasers
SOP Outline

1. Laser Supervisor / Principal Investigator

Printed Name:_____

Department:_____

2. Laser System Identification

Laser Name/Manufacturer/Model:_____

Laser Classification:_____ Is the beam visible? (Yes or No _____

3. Introduction

Indicate the physical location of this laser including the building and room number:_____

_____

Provide a brief description of the overall mode of operation of this laboratory including the total number of active lasers and a description of the laser research being conducted.

_____

_____

4. Safe Start-Up Procedures

Prior to laser operation, the following start up procedures will be implemented to ensure safety.

1. _____
2. _____
3. _____
4. _____

THIS LASER MUST NEVER BE LEFT UNATTENDED DURING OPERATION UNLESS THE FOLLOWING PROCEDURES ARE IMPLEMENTED.

_____

_____

_____

5. Safe Shut-Down Procedures

The following non-emergency shut-down procedures will be implemented to ensure safety.

1. _____
2. _____
3. _____

Is a main emergency shut off available on the laser unit or in the laboratory? (Yes/No)_____

Is the Emergency Shut off Clearly Marked? (Yes/No)_____

6. Laser and Laboratory Access Control

Describe access to lab (key, card key, combination, etc.) _

Do unauthorized personnel have access to the laser laboratory? (Yes/No)____

Does the laser use a key or access panel to prevent unauthorized laser operation?_____

Describe procedures to prevent unauthorized laser operations:_____

_____

7. Describe Alignment Procedures

All laser users must be aware that most laser accidents occur during alignment. Precautions must be taken to prevent exposure during alignment. Alignment procedures must be performed in accordance with manufacturer's instructions, and at the lowest possible power output. Alignment procedures should include all of the following;

- Notify lab personnel of intended alignment procedures.
- Ensure only authorized personnel are in the area.
- Use appropriate laser protective eyewear.
- Follow standard safe operating procedures listed below.
- Remove laser housing, cover or enclosure as needed.
- Override the laser interlocks and commence alignment.
- Close aperture when cleaning optics.
- Operator will not leave laser unattended until housing and enclosures are in place and interlocks are operational.

Please use the following space to specifically describe alignment procedures and precautions associated with the alignment of this laser system._____

_____

_____

_____

_____

_____

_____

_____

_____

8. Laser Warning Systems

Describe Laboratory Entrance Warning Signs:_____

_____

_____

Describe Laser Control Area Warning Signs:_____

Please contact EHS if you need assistance establishing appropriate warning systems.

9. Beam Controls

Is the laser beam path open, enclosed, or partially enclosed? _____

Please describe the enclosure if applicable: _____

Is the enclosure equipped with interlocks? (Yes/No) _____ Describe the interlock system:

Identify required exposure controls when operations bypass the interlock: _____

How is the beam terminated? _____

Are other beam controls in use? (curtains, window covers, etc.) Please describe: _____

10. Exposure Controls

Are the laser protective housing and service panel equipped with interlocks? (Yes or No) _____

Identify required exposure controls when operations bypass these interlocks: _____

Identify established procedures for directly viewing the beam: _____

Describe established procedures for using optical viewing aids: _____

Describe established procedures for operating two lasers in a laser laboratory or control area.

11. Laser Protective Eyewear

Provide the following information for the protective eyewear needed for this laser:

Eyewear Manufacturer	Optical Density (OD)	Wavelength or Range (nanometers)	Storage Location

12. Emergency Procedures

Authorized laser operators and laser laboratory occupants must be familiar with specific laboratory and building emergency procedures. Authorized laser operators must be familiar with evacuation plans, locations for emergency laser shut off, procedures for fires or medical emergencies. Emergency shut off and emergency procedures include: (Check all that apply)

☐ On/Off switch or key control on laser control panel.

☐ External emergency power off button on wall close to the entryway or other location.

☐ Circuit Breaker Box. (Breaker controlling the laser operation is clearly marked)

☐ Replace beam stop.

☐ EHS emergency procedures are posted near the telephone in the laser laboratory.

Please identify any laboratory specific emergency procedures:_____

_____

_____

_____

13. Maintenance

Only specially trained personnel are permitted to perform maintenance on lasers and laser systems. All equipment including safety interlocks, alarms, warning lights, and relief devices will be maintained, calibrated and tested on a regular basis in accordance with manufacturers recommended intervals. All equipment maintenance will be logged as described below.

_____

_____

_____

If maintenance is to be completed by Mines personnel, please identify the person responsible for completing the maintenance and their qualifications for properly and safety maintaining laser equipment. _____

_____

_____

14. Temporary Laser Facilities

Describe provisions for protecting laser operators, students and spectators when a temporary laser facility is established. _____

_____

EHS must be notified whenever a Principal Investigator establishes a temporary laser facility.

15. Non-beam Hazards

Identify all anticipated non-beam hazards and the controls such as personal protective equipment, ventilation, or electrical safety procedures to prevent injury.

16. Laser Users

Only authorized personnel may operate the laser system identified by this SOP. Authorization is granted upon completion of the following:

- **Review of the laser system operating manual**
- **Laser specific training provided by the Principal Investigator.**
- **General Laser Safety Training provided by EHS**
- **Review this laser system SOP.**
- **Certification that the operator has completed these requirements by signing this SOP.**

By signing this Laser System Standard Operating Procedure, I Certify I Have Received All Required Training, And Fully Understand The Safety Procedures and Safe Operating Procedures Identified In This Laser System Standard Operating Procedure and the Operating Manual For This Laser System.

Operator's Printed Name	Operator's Signature	Academic Department	Principal Investigator's Name	Principal Investigator's Signature	Authorized Independent Laser Operator (Yes/No)

Appendix C

Key Terms and Definitions

Laser Safety Manual
Key Terms and Definitions

Accessible Radiation – Radiation to which it is possible for eye or skin exposure during normal laser operations.

Attenuation – The decrease of radiant power of a laser beam as it passes through absorbing media.

Authorized Laser Operator – A person who has attended an EHS Laser Safety Training class, reviewed and signed the laser SOP, reviewed the operating manual and received laser specific training from the Principal Investigator.

Authorized Personnel – Laser laboratory visitors, assistants, or researchers who require access to the laser control area but are not authorized to operate the laser. Authorized personnel must receive familiarization training from the Principal Investigator prior to entering the laser control area.

Aversion Response – Movement of eyelid or head to avoid exposure to a laser.

Beam – Collection of rays which may be parallel, divergent or convergent.

Control Area – Laser laboratory or laser area where access is limited due to the laser hazards.

Diffuse Reflection – Change in the spatial distribution of a laser beam when reflected in multiple directions usually from a non-reflective surface.

Independent Laser Operator – Authorized student laser operators who received authorization from the Principal Investigator to operate a class 3b or class 4 laser system without supervision. Independent laser operators must be identified on the signature page of the laser system SOP.

Interlock – A mechanism where the electrical power or physical operation of a laser system is interrupted in a fail safe mode as a result of a potential unsafe condition.

Laser – A device which generates a directional, coherent, single wavelength of light with a narrow spectral range.

Laser System – An assembly of optical, electrical and mechanical components all associated with an individual laser.

Maximum Permissible Exposure (MPE) – The level of laser radiation a person may be exposed without hazardous effects or adverse biological changes to the eyes and skin.

Nominal Hazard Zone – The space which the level of the direct, reflected, or scattered radiation during normal operations exceeds the maximum permissible exposure. Exposures beyond the boundary of the nominal hazard zone are below the maximum permissible exposure level.

Laser Laboratory – A laboratory where a class 3 or class 4 laser is used.

Optical Aided Viewing – Viewing a laser source with an optical device such as an eye loupe, hand magnifier, microscope, binoculars, telescope, etc. Optically aided viewing does not include viewing with corrective eyewear or with direct image converters.

Optical Density (OD) – Logarithm to the base ten of the reciprocal of the transmittance. The higher the optical density, the lower the transmittance.

$OD=-\log_{10}\tau_\lambda$ OR $OD=\log_{10}[Hp/MPE]$

τ_λ = Laser Transmittance

Hp= Exposure in W/cm^2 or J/cm^2

MPE = Limit in same units as Hp

Protective Housing – An enclosure surrounding the laser or laser system that prevents access to laser radiation above the applicable maximum permissible exposure. The aperture where the useful beam is emitted is not part of the protective housing. The protective housing may enclose associated optics and workstation and limits access to radiant energy emissions and to electrical hazards associated with components and terminals.

Pulse Duration – The duration of a laser pulse, usually measured at the time interval between the half-power points on the leading and training edges of the pulse.

Pulse Repetition Frequency – The number of pulses occurring per second, expressed in hertz.

Pulsed Laser – A laser which delivers energy in the form of a single pulse or a train of pulses. Each pulse has time duration of less than 0.25 seconds.

Q-Switch – A devise for producing a very short intense laser pulse by enhancing the storage and delivery of electrical energy in and out of the lasing medium.

Specular Reflection – A mirror like reflection.

Transmittance – The ratio of transmitted power to incident power.

Wavelength – The distance between two successive points on a periodic wave which have the same phase.