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Jefferson Lab
Thomas Jefferson National Accelerator Facility

Operational Safety Procedure Review and Approval Form # 69180
(See ES&H Manual Chapter 3310 Appendix T1 Operational Safety Procedure (OSP) and Temporary OSP Procedure for Instructions)

Type:	*LOSP* Click for OSP/TOSP Procedure Form Click for LOSP Procedure Form
Serial Number:	*ACC-17-69180-LOSP*
Issue Date:	*8/7/2017*
Expiration Date:	*7/7/2020*
Title:	*LERF Drive Laser Enclosure*
Location: (where work is being performed) Building Floor Plans	*18 - Low Energy Recirculator Facility (LERF) - 214A*
Location Detail: (specifics about where in the selected location(s) the work is being performed)	*Drive laser cleanroom*
Risk Classification: (See ES&H Manual Chapter 3210 Appendix T3 Risk Code Assignment)	Without mitigation measures (3 or 4): *3* With mitigation measures in place (N, 1, or 2): *1*
Reason:	This document is written to mitigate hazard issues that are : ***Determined to have an unmitigated Risk code of 3 or 4***
Owning Organization:	*ACCASA*
Document Owner(s):	***Benson, Steve (felman@jlab.org)*** Primary ***Zhang, Shukui (shukui@jlab.org)***

Supplemental Technical Validations

Lasers Class 3B or 4 (Ultraviolet, Infrared, and Visible Light)   (Bert Manzlak, Jennifer Williams)
Fire Protection   (Tim Minga)

Document History

Revision	Reason for revision or update	Serial number of superseded document
1	*Update to electronic version*	

Lessons Learned	Lessons Learned relating to the hazard issues noted above have been reviewed.
Comments for reviewers/approvers:	

Attachments

Procedure: ***LSOP214ar5.pdf***

THA: ***THA for DLE.pdf***

Additional Files:

Review Signatures	
Additional Authorization : Fire Protection - other than current engineered safeguards or fire watch	**Signed** on 8/1/2017 4:49:00 PM by Tim Minga (minga@jlab.org)

Approval Signatures	
Division Safety Officer : ACCASA	**Signed** on 8/2/2017 7:00:24 AM by Harry Fanning (fanning@jlab.org)
Org Manager : ACCASA	**Signed** on 8/7/2017 11:13:06 AM by Mike Spata (spata@jlab.org)
Safety Warden : Low Energy Recirculator Facility (LERF) - 214A	**Signed** on 8/2/2017 7:00:30 AM by Harry Fanning (fanning@jlab.org)
Subject Matter Expert : Lasers Class 3B or 4 (Ultraviolet-> Infrared-> and Visible Light)	**Signed** on 8/2/2017 8:06:24 AM by Bert Manzlak (manzlak@jlab.org)

Laser Operational Safety Procedure (LOSP) Form

(See ES&H Manual Chapter 6410 Appendix T1
Laser Operational Safety Procedure)

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Serial Number: ______________________________

(Assigned by ESH&Q Document Control x7277)

*Attach the Task Hazard Analysis (THA) related to this procedure

Issue Date:		**Expiration Date:**	
Title:	LERF Drive Laser Enclosure		
Location:	Building 18 (LERF) Room No. 214a		
Description of Project	Operation of the LERF injector drive laser		
Document Owner(s):	Stephen Benson, Shukui Zhang	**Date:**	6/26/17

Laser Inventory

Laser Serial #	Laser Class	Wavelength(s)	Maximum Power/Energy
1. 148	4	1.064 microns	1 W/0.0133 µJ @ 75 MHz
2. 2599-1	4	0.532 microns	30 W/0.4 µJ @ 75 MHz

Approval Signatures:	Print Signature	Date:
Laser System Supervisor:	Stephen Benson	
Laser Safety Officer:	Bert Manzlak	
Division Safety Officer	Harry Fanning	
Department or Group Head:	Fulvia Pilat	
Other Approval(s):		

Document History:

Revision:	Reason for revision or update:	Serial number of superseded document
5	Update format to electronic version	FEL-14-005 LOSP

Distribution: ESH&Q Document Control (x7277, MS6B); affected area(s); Document Owner; Division Safety Officer

Introduction – In areas containing more than one laser, define operational sequence or parameters.

Room 214A of the Low Energy Recirculation Facility (LERF) in building 18 at Jefferson Lab (hereafter referred to as the Drive Laser Enclosure, or DLE) contains a Class 4 oscillator-amplifier laser which drives the LERF linear accelerator injector (see figures 5.1 and 5.2). Laser hazards are present both in the DLE and in the accelerator enclosure. These hazards are mitigated by a controls system, the Laser Personnel Safety System (LPSS, described later) that prevents the laser from operating unless the room is secured and by laser safety eyewear. This Laser Operational Safety Procedure (LOSP) gives a description of the laser used, the hazards present, a description of the laser enclosure and the procedures for safe operation.
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Personnel Only those authorized by the LSS are permitted to enter the location noted on the cover sheet of this document.	List: • Training and qualification requirements (including refresher training). • Medical requirements. • Spectator protection requirements.

Users of the drive laser in this user lab must have completed the EH&S Orientation to Jefferson Lab (SAF100), General Employee Radiation Training (GERT, which is SAF800), (or, alternatively, Radiological Worker Training I, which is SAF801F), and Oxygen Deficiency Hazards Training (ODH, which is SAF103). They must also satisfy the following requirements before working in the DLE:

1. Be qualified for laser use by the Jefferson Lab Occupational Health Physician as detailed in section 6410 of the Jefferson Lab EH&S manual. This qualification must be done once during the user or employee's time at Jefferson Lab and must be completed before the users operate any Class 3B or Class 4 lasers (MED02 or equivalent).
2. Read over the laser safety section of the Jefferson Lab EH&S manual. The web link for this is: http://www.jlab.org/ehs/ehsmanual/manual/6410.html
3. Take a laser safety course administered by the Laser Safety Officer (LSO) at Jefferson Lab (SAF114O).
4. Read this document.
5. Have a safety walk-through of the user lab carried out by the laser system supervisor (LSS) for the LERF (now Steve Benson, the course is SAF115DLE) and pass a test to verify that they have understood how to use the lab in a safe manner.

Only personnel qualified for the DLE may make up the DLE LPSS or be in the DLE when it is in LASER PERMIT. A list of qualified laser users for the DLE is on the operations server.

Other Jefferson Lab personnel or outside visitors may only enter the DLE when the room is in an OPEN state (no laser-in-operation lights illuminated outside the room or in the anteroom). Visitors to the LERF facility must be accompanied at all times by someone with ODH and GERT or better training. The laser safety officer (LSO) for Jefferson Lab may grant exceptions to this rule in special circumstances.

Non-JLAB maintenance and installation personnel for Class 3B or Class 4 laser systems may be in the DLE when it is made up if they are escorted by an approved laser user and they have provided verification to the Jefferson Lab LSO that they have completed laser safety training at their company. They are permitted to use laser protective eyewear (LPE) specified by their employer for use with the laser being installed or serviced. When non-JLAB personnel are doing such work in the DLE, the lab must be posted with the blue laser maintenance notice sign provided in the document holder on the door.

Laser	Define: • Laser system specifications. • Define laser system components. • Copy of laser operating manuals or reference the location of the manual(s).

There are presently two lasers (an oscillator and an amplifier) in the drive laser enclosure that qualify as a class 4 laser. Note that the oscillator-amplifier has several modes of operation depending on the setup, 74.85 MHz vs. 748.5 MHz and two amplifier stages or four amplifier stages. The micropulse repetition rate can be changed to binary fraction of the oscillator frequency.

Other lasers used in the user lab are Class 3R or Class 2 helium-neon lasers used for alignment. The following are the details on the oscillator and amplifier:

Laser #1 – Oscillator

Type of laser	Mode-locked picosecond Nd:YVO_4
Manufacturer	Time-Bandwidth Products. Halle Zeppelin 1.OG Technoparkstrasse 1 CH-8005 Zurich, Switzerland 41 1/445-3120 Info@tbwp.com
Model	GE-100-VAN-ETL-CLX-75/750
Serial numbers	148
Wavelength 1	1.06 µm
Power at Wavelength 1	1.1 W
Pulse rate	74.85 MHz & 748.5 MHz
Beam diameter ($1/e^2$)	2 mm
Beam divergence ($1/e^2$),	1 mrad (H) & 2.5 mrad (V)

Laser #2 – Amplifier

Type of laser	Amplified Mode-locked picosecond Nd:YVO_4
Manufacturer	Q-Peak. 135 South Road Bedford, MA 01730 USA www.qpeak.com
Model	TB-MPV-532 ML 40H
Serial numbers	2599-1
Wavelength 1 (λ_1)	1.06 µm
Power at λ_1 (2 Amps)	30 W
Power at λ_1 (4 Amps)	60 W
Wavelength 2 (λ_2)	0.53 µm
Power at λ_2 (2 amps)	10 W

Power λ_2 (4 amps)	30 W
Pulse rate	74.85 MHz & 748.5 MHz, 37.425, 18.7125, 9.356, 4.678, 2.34, 1.17, and 0.585 MHz
Beam diameter ($1/e^2$)	1.5– 2 mm
Beam divergence ($1/e^2$)	0.5 mrad
NHZ for eyes (m) (4 amps)	1748 (0.53 µm), 3496 (1.06 µm)
NHZ for skin (m) (4 amps)	276 (0.53 µm), 175 (1.06 µm)

Notes: The Drive laser may be modelocked at 74.85 MHz or 748.5 MHz and emits 35–45 psec. pulses with up to 400 nJ of energy in the green. The laser also emits up to 30 W of infrared light with two amplifier stages and 60 W of infrared light with four amplifier stages. The 30 W beam exits the laser enclosure before being doubled in a crystal. The 60 W Beam is sent through the doubling crystal inside the laser enclosure. A dichroic filter usually stops 99.5% of this power inside the laser enclosure so that the normal infrared output power is less than 100 mW. A diagnostic port allows <1 mW of infrared light to escape from one of the relay mirrors for monitoring (class 1). Since the pulses occur at such a high frequency, the light output for full frequency output is continuous as far as eye safety is concerned (see section 7.1) as long as the repetition rate is greater than 6 MHz in the IR and 2.5 MHz in the green. The laser system consists of a mode-locked oscillator with a diode pumped Nd:YVO_4 chip as its gain medium, passive SESAM modelocking, an electo-optic controller for modifying the pulse structure, a diode pumped pre-amplifier, two or four stages of diode pumped amplifiers, a doubling crystal for generating the green light, and a set of diagnostics for characterizing the beam. The laser cover is interlocked to prevent operation with the cover open. The laser has all safety features necessary under CDRH guidelines[1].

See the attachments to this document for a description of safety features and safety labels.

Hazards and Mitigation	Define: • Laser-specific hazards. • Occupational exposure hazards beyond laser light (e.g. fumes, noise, etc.). • Credible non-beam hazards (e.g. environmental hazards). • Describe all required personal protective equipment ES&H Manual Chapter 6410 Appendix T2 Laser Personal Protective Equipment (PPE) (include: clothing requirements (e.g.: no reflective jewelry, etc.).

The drive laser can produce a hazardous diffuse reflected beam in addition to the more obvious hazards from the direct or specularly reflected beam. It also poses a significant skin hazard for direct exposure. Cloth or paper can ignite quickly when exposed to the laser beam presenting a fire hazard. The most dangerous time is when the laser is being aligned. Safety eye wear has been chosen to allow the green, doubled Nd:YVO_4 beam to be seen dimly so that one knows where the beam is when wearing laser safety eyewear. It is very important to remember that this beam, though it appears very dim, is capable of burning skin in less than a second when running at full power. The laser also emits a powerful infrared beam that is filtered out in a dichroic filter and is therefore usually not sufficiently powerful to burn skin (<100 mW). The high power IR beam before the filter can cause serious deep-tissue burns. Great care must be exercised when working with the infrared high-power beam. Since it is completely invisible, it is imperative that laser safety eyewear be worn at all times when working with this laser. Appropriate laser safety eyewear is available in the anteroom of the DLE.

It is important to add that the laser is remotely controlled so turning off the laser does not ensure safety. The keys must be removed, or the LPSS must be safed before one may remove his or her laser safety eyewear.

[1] See ANSI Z136.1-2004 Section 4.3 for description of necessary engineering controls on Class 3 and 4 lasers.

Nominal Hazard Zones

To illustrate the laser hazard more fully it is useful to calculate the Nominal Hazard Zone (NHZ) for the laser, both for a specular reflection and for a diffuse reflection. This is done for both eye and skin exposure. For a specular reflection the nominal hazard zone radius is given by

$$R(m) = \frac{1}{100\Phi}\sqrt{\frac{1.27P}{MPE}}$$

where Φ is the full angle divergence of the laser beam, P is the laser power in Watts, and MPE is the maximum permissible exposure in W/cm^2. For a diffuse reflection with an albedo ρ and scatter at an angle θ, the nominal hazard zone radius is given by:

$$R(m) = \frac{1}{100}\sqrt{\frac{P\rho\cos\theta}{\pi MPE}}$$

In the table below we show the calculated NHZ radii for specular and diffuse reflections for the advanced drive laser. For the diffuse reflection we assumed a worst-case albedo of unity and a worst-case angle of 0°.

Table 4.1, Direct and diffuse reflection nominal hazard zones for the drive laser. All distances are in meters.

	Specular Reflection NHZ Radii		**Diffuse Reflection NHZ Radii**	
Laser	Ocular (m)	Dermal (m)	Ocular (m)	Dermal (m)
Adv. Drive laser Oscillator	105	7	0.08	0.006
ADL Amp(1 μm)	3496	175	0.87	0.044
ADL Amp(0.5 μm)	1750	276	0.44	0.069

The nominal hazard zone for this laser (when the IR is dumped inside the laser head) is 1750 meters for the optical hazard zone and 276 meters for the dermal hazard. Even the diffuse scattered nominal hazard zone is over 44 cm for the optical hazard so a near miss is almost as dangerous as a direct hit for this laser. This is why laser safety eyewear is mandatory at all times, even when the laser is turned off, since the laser is remote controlled and might come on by remote command.

Dermal protection must also be considered. When feasible, beam covers should be used to prevent accidental exposure to the high-power beam. Alignment must be done at low power (<500 mW) and the power must be brought up slowly. Lab coats can be used to reduce the possibility of dermal damage from accidental strikes as well.

The laser beam can enter the vault through an optical transport line. Work on this transport line requires lock, tag, and try (LTT) on the laser. Either the machine protection shutter or the drive laser AC power plug must be locked into a safe state using an approved LTT device and the personnel doing the work must verify that the laser cannot get past the shutter and that the shutter cannot be opened.

Appropriate Optical Density and Required Use of Laser Safety Eyewear

Engineered controls are used where possible to eliminate the laser hazard. This cannot be done at all times for all laser systems. ***In the case that direct access to the laser beam is required, the best way to ensure that no harm comes to the user's eyes is to wear appropriate safety laser safety eyewear at all times when working with a laser and to be aware of where the high-power beams are. Laser eyewear use is mandatory in any room in building 18 when a Class 3b or 4 hazard is present.***

The calculations for the required laser safety eyewear attenuations are in the "Required Calculations" section. A summary of the eyewear approved for use with the drive laser is listed in Table 4.2. Laser safety eyewear with an optical density greater than 5 at both 1064 nm and 532 nm is sufficient for all operating scenarios that do not entail viewing devices such as telescopes or binoculars. Note that the maximum permissible power levels vary as the ¾ power of drive laser repetition rate for repetition rates less than 4.678 MHz in the IR and less than 2.34 MHz in the green. Since the power is usually much less at these frequencies the required optical densities are not increased but it is important to note that the lower frequencies are not safer even though the power is less.

Table 4.2. Laser safety eyewear requirements for the advanced drive laser (all values rounded up to nearest integer). The optical density is highest for the 4-amplifier operation but it is almost as high when operating with a failed machine protection system and low frequency.

Laser@wavelength	Power output	Optical density
Nd:YVO_4 @1064 nm (2 amp.)	25 W	5
Nd:YVO_4 @1064 nm (4 amp.)	60 W	5
Nd:YVO_4 @1064 nm (0.585 MHz, 30 μJ)	18 W	5
Nd:YVO_4 @532 nm (2 amp.)	10 W	4
Nd:YVO_4 @532 nm (4 amp.)	30 W	5
Nd:YVO_4 @532 nm (0.585 MHz, 15 μJ)	9 W	5

Pay careful attention to the laser safety eyewear selection. The appropriate laser safety eyewear should have both green and orange colored tape. It is a very good idea to also read the label on the laser safety eyewear to make sure that they match the required attenuation for the laser being used. The optical attenuation must be at least OD 5 at both 1064 and 532 nm.

Non-beam hazards

The non-beam hazards due to the laser, in order of their likelihood, are fire, electrical shock, and burns.
There are no exposed voltages higher than 50 V in the laser. There are no user-serviceable parts in the laser power supplies. Electronic chassis have 120 VAC present in them. It is important to follow the safety instructions of the manuals. Only qualified personnel shall do work on electronic parts of the laser using written procedures. Interlocks on the power supply and covers shall not be defeated. Only class 1 and 2 electrical work is allowed. Lock, Tag, and Try (LTT) may be accomplished for the laser power supply by unplugging the power supply. The cords are in sight of the electronics.
It is important to keep any flammable materials away from the beam at all times. The laser user should be aware at all times of the location and function of the fire extinguishers in the DLE (next to the door). There is a smoke

detector in the clean enclosure covering the laser that will shut down the laser if it goes into alarm. It must be checked at 6 month intervals or whenever the LPSS is modified. The Fire Systems SMEs in facilities management should be contacted prior to testing. They are Tim Minga, (minga@jlab.org, (757) 371-1687) and Robert Myles (myles@jlab.org, (757) 270-9071).
The drive laser enclosure is rather small and can be quite congested. Care must be taken when carrying out measurements that restrict movement or egress. Trip hazards may be present when this work is done.

Laser Environment System designs, including interlocks, require hazard evaluation review by SME.	Define: • Layout of the laser controlled area and/or table. (Show beam location in relation to user (waist height preferable).) • Interlock schematic (or similar) (including smoke detector interlocks). • Room lighting conditions during laser use and alignment procedure(s). • Targets. • Primary and all likely beam paths (open or enclosed).

The laser is used to extract electrons from a semiconductor crystal inside the electron gun, which is located in the accelerator vault. The electrons are then sent into the main beamline for use in the free-electron laser accelerator. The laser light is transported from the DLE to the accelerator vault through a metal transport line (see figure 5.1). If the integrity of this beamline is compromised, e.g. work is being done on the power supply, and the laser supply cannot be locked out due to work being done on the laser, the MPS shutter in the DLE shall be locked out. A detailed layout of the laser system on the optical bench in the DLE is shown in figure 5.2.
The DLE is a controlled area during laser operations and the laser is interlocked to the room safety system. A key on the laser power supply can also be used to positively shut down the laser. During laser operations only authorized users will be allowed in the room. The laser is mounted on an optical bench. The diagnostics and matching optics are in a plane on the table at a height of 36 inches off the floor. There are a couple of periscopes that are covered as well.
The DLE has only one entry and exit point. The integrity of the lab must be maintained. To ensure this, a magnetic lock secures the door when the interlock is energized. Entry to the lab occurs by first opening a door into the anteroom. After donning protective eyewear and disposable footgear, one enters the DLE proper through a second door. If the interlock has been energized, entry is permitted by bypassing the interlock, either by (1) entering the proper code into the keypad, or (2) requesting a user already in the DLE to temporarily bypass the interlock. Do not open the door until everyone in the anteroom has put on laser protective eyewear.
The lighting in the DLE shall be typical of office lighting during typical alignment and setup activities. Only when aligning with laser power levels typical of a Class II laser or when using low light level CCD cameras should the lights be dimmed. For hazard calculations however it is assumed that the pupil size is 7 mm (fully dilated).
Crash buttons that bring the DLE to a safe state are available in the anteroom and on the LPSS chassis. When a laser operator feels that an unsafe condition exists he or she must press the crash button.
The fire protection system is a layered system that includes:
1. **Detection systems** such as local smoke detectors in the laser personnel safety system (LPSS), building smoke alarms connected to the building fire alarm panel, and manual pull boxes and,
2. **Suppression systems** consisting of wet pipe sprinklers throughout the upper level of the LERF and portable fire extinguishers.
The LPSS smoke detector not only provides a machine protection function (personnel are unlikely to be present when they detect smoke) they also reduce the likelihood of fire spreading due to the drive laser. The LPSS smoke detector is connected to the building Fire Alarm Control Panel (FACP) and is programmed to activate a "trouble" signal on the FACP if it detects smoke. The smoke detector that has been activated by smoke will

display a slow flashing red LED on the plastic cover of the detector. The laser user must find the cause of the smoke production and eliminate it before resuming laser beam delivery.
The building smoke detectors activate an alarm signal in the FACP that will sound the building audible alarms. If an LPSS smoke detector is activated, the building audible alarm will not sound. The building smoke detectors are connected to the FACP in the LERF lobby and are monitored by the MCC and Security Guard Post 2 at the main gate. They do not affect the state of the accelerator.
Manual Pull boxes are present near the building exits and should be used when smoke or a fire is observed but the alarm has not yet activated. Operating a manual pull box is the fastest and best way to evacuate the building and notify notify the MCC and Security guards.
A portable fire extinguisher is present in the DLE. Anyone who is trained and judges that the situation can be handled, should use the Fire Extinguisher. It is class C and can be used to extinguish small fires.

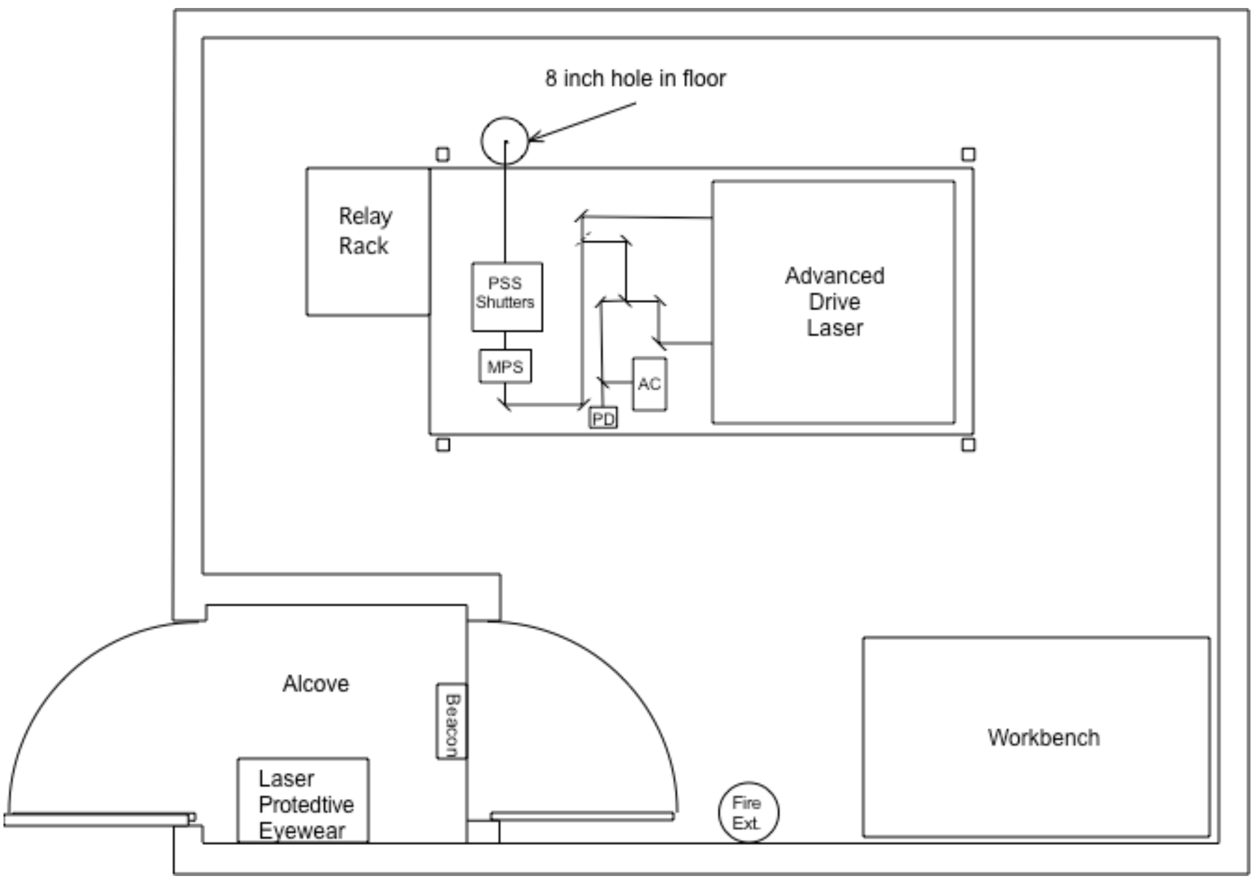


Figure 5.1 Illustrutive layout of Drive Laser Enclosure with LPSS chassis, fire extinguisher and optical bench pointed out. The chiller and power supplies for the Advanced Drive Laser are on the floor below the optical bench.

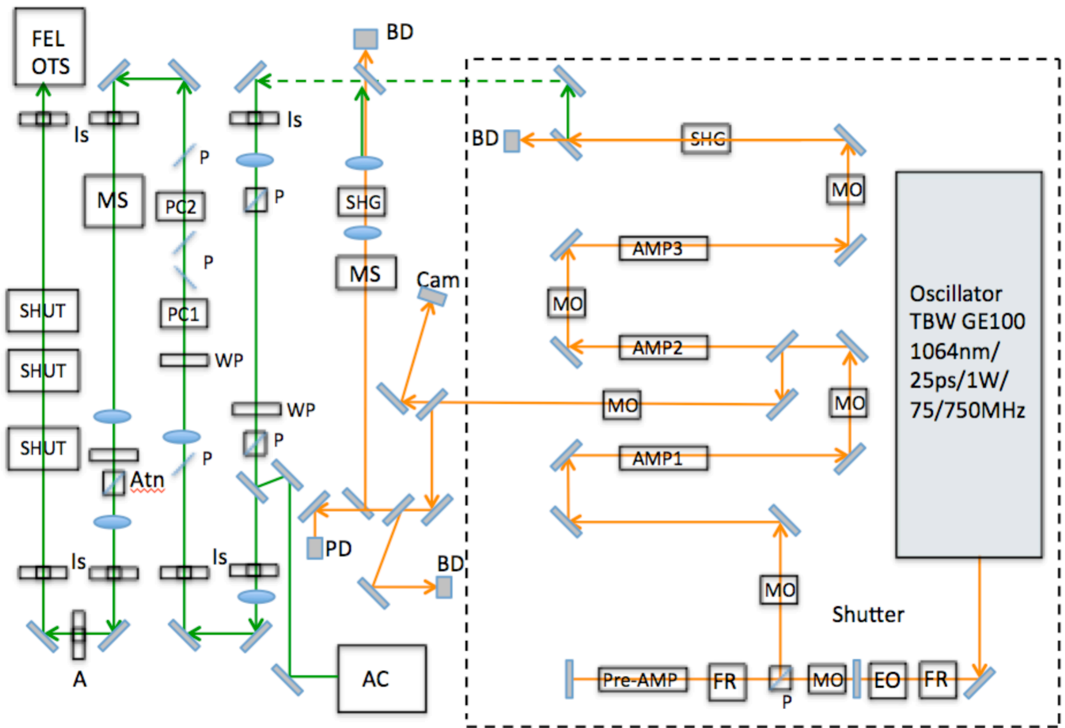


Figure 5.2. Optical layout of the Drive laser system mounted on the optical bench in the Drive Laser Enclosure as of July 2017. The oscillator beam is isolated from the amplifier with a Faraday rotator (FR). It is gated using an electro-optic cell (EO). The beam is amplified in a pre-amplifier (Pre-AMP) and then amplified in either one or three power amplifiers (AMP1, AMP2, and AMP3). The beam is then frequency doubled and sent through another pulse gating Pockel cell (PC1, PC2), and attenuator (Atn), and matching optics. It then goes through an aperture (A), which is imaged to the cathode by the optical transport system (FEL OTS). Mechanical shutters (MS) are used to block ghost pulses and protect optics. There are three safety shutters (SHUT), one for the Machine Protection System and two for the Personnel Protection System. Diagnostics (photodiodes and an autocorrelator) monitor the beam timing at different time scales. Polarizers (P) are used at different locations to control beam polarization.

Written Procedure for Use and Alignment	Provide: • All process steps – including unattended operation controls. • All process steps for detailed alignment – Include manufacturer's protocols for alignment. • Maintenance and service. • Off-normal and emergency procedures (e.g. beam loss, fire).

Maintenance and Certification

Only approved Jefferson Lab personnel may work on the LPSS (including wiring to the interlocks). The LPSS system owner (currently Kevin Jordan) grants approval on the basis of appropriate training. After work is completed, checks of the functionality must be completed before the drive laser is run. If work is done on the LPSS, the system must be re-certified. Modification of the LPSS by unauthorized personnel is cause for disciplinary action. An Approved Laser User (preferably an FEL Laser Operator) must certify the LPSS every 6 months even if no work has been done on it. The Fire Systems SMEs in facilities management should be contacted prior to testing the LPSS smoke alarm. They are Tim Minga, (minga@jlab.org, (757) 371-1687) and Robert Myles (myles@jlab.org, (757) 270-9071).

Any certification of any LPSS in the LERF must be kept on file in the LERF control room and must be logged in the LERFLOG. In addition, the certifier must check the laser safety eyewear in the anteroom for any damage that would compromise their integrity or ease of use. If any scratches, cracks, films, or discoloration on the lenses are found, the LPE must be taken out of service.

The laser beam can enter the vault through an optical transport line. Work on this transport line requires lock, tag, and try on the laser. If the drive laser cannot be locked out, the machine protection shutter must be locked out and the personnel doing the work must verify that the laser cannot get past the shutter and that the shutter cannot be opened.

Every month all fire extinguishers must be checked for proper pressure, intact pin and seal, and overall condition and documented by dating and initialing the card attached to the extinguisher.

Off-Normal Procedures

In the event of fire in the DLE, a fire extinguisher in the room may be used if the person is properly trained and so chooses, and his or her escape route is clear. If the fire cannot be extinguished in this manner, the user should leave the room, pull the nearest fire alarm box (across from the copier at the top of the stairs) and exit the building. If the fire alarm sounds due to a fire outside of the DLE, all personnel must evacuate the building. In the event of a building fire alarm, the drive laser operator crashes the LPSS (push the red crash button on the LPSS box or in the anteroom) and then must immediately exit the building and gather at the muster point (just outside the main door). The operator should then dial 9-911 and report the fire. Note that calling 9-911 from a land line will automatically notify all on-site emergency personnel including the guards in the guard shack.

In the event of a building ODH alarm the operator must exit the lab. The crew chief in the MCC must be contacted at x7045 or 9-630-7050 once the building is evacuated. After an ODH event is cleared and the building has been authorized for re-entry, the ODH sensors should be checked and recalibrated if necessary.

In the event of an injury caused by laser light, the following procedures must be followed:

Ocular Exposure During Normal Business Hours

1. The victim should be initially evaluated by JLab Occupational Medicine. If the situation seems critical, call 9-911 and then Occupational Medicine (269-7539 or page 584-7539). The victim should remain still with both eyes closed while waiting for the ambulance and Occupational Medicine staff to arrive at the scene. If the situation is not critical, call Occupational Medicine only and let them know that the victim is being transported to Occupational Medicine. Do not allow the victim to drive.
2. Occupational Medicine will administer first aid. This typically entails taping ocular protective cups over both eyes and then transporting the victim to a hospital emergency department or ophthalmologist, depending on the severity of the injury.
3. Occupational Medicine will also ensure that the victim is subsequently examined by an ophthalmologist.
4. After the victim recovers from the acute injury, Occupational Medicine will provide her/him with a letter explaining the injury.
5. The LSO must be contacted as soon as reasonable and an investigation should be started to study the causes of the accident and future precautions necessary to prevent any new accidents.

Ocular Exposure After Normal Business Hours: Same as above except that Occupational Medicine will not be involved initially. All victims should be transported to a hospital emergency department. Transport can be via ambulance or coworker, depending on the apparent severity of the injury. Occupational Medicine should be informed on the next business day.

Skin Exposure During Normal Business Hours

1. The victim should be initially evaluated by JLab Occupational Medicine. If the situation seems critical, call 9-911 and then Occupational Medicine (269-7539 or page 584-7539). If bleeding is present, it should be controlled using direct pressure from a gloved hand over gauze. If the situation is not critical, call Occupational Medicine only and let us know that the victim is *en route* to Occupational Medicine.
2. Occupational Medicine will administer first aid. This typically entails controlling bleeding and applying a dressing.
3. After initial evaluation by Occupational Medicine and/or the emergency department, Occupational Medicine will ensure appropriate follow-up.
4. The LSO must be contacted as soon as reasonable and an investigation should be started to study the causes of the accident and future precautions necessary to prevent any new accidents.

Skin Exposure After Normal Business Hours: Same as above except that Occupational Medicine will not be involved initially. If the situation warrants (e.g. if the skin burn is more than a blister), the victim should be initially evaluated at a hospital emergency department. Occupational Medicine should be informed on the next business day.

Normal operating procedures:

Alignment procedures begin with a rough alignment of the oscillator laser at reduced power. The operator must follow the procedure in the manual for the oscillator. The amplifier alignment procedure is done rarely and must be carried out by an expert. All phases of the alignment should occur at full lighting levels in the lab. General rules for alignment are as follows:

Before Alignment starts:

1. To reduce accidental reflections, remove watches, rings, dangling badges, necklaces, and reflective jewelry before any alignment activities begin. Use non-reflective tools if possible.
2. Limit access to the room/area to authorized personnel only. No multi-tasking!
3. Consider the need for additional personnel during alignment. It might go smoother with two people.
4. Gather all equipment and materials needed prior to beginning the alignment.
5. Remove all unnecessary equipment—tools, combustible material (if fire is a possibility) to minimize the possibility of stray reflections and non-beam accidents.

Rules during alignment

1. Co-axial low power lasers should be used when practical for alignment of the primary beam.
2. Laser Protective Eyewear shall be worn at all times during the alignment.
3. There shall be no intentional intra-beam viewing with the eye.
4. Reduce the beam power through the use of neutral density filters, beam splitters and dumps, or reducing power at the power supply. Avoid the use of high-power settings during alignment as much as is practical.
5. Keep the laser beam under control. Close the shutter when moving optics, keep mounts secured to the table. This takes a bit longer but pays off in results and safety.

6. Areas where the beam leaves the horizontal plane shall be labeled.
7. Terminate stray or unused beams.
8. View invisible beams with IR/UV cards, business cards, viewers, thermal fax paper, or IR viewer. Be aware that specular reflections off some of these devices are possible, and that they may smoke or burn.
9. Remember to replace covers, beam blocks and barriers after alignment.

Normal operation of the lasers should go according to the following procedure:

1. Authorized personnel enter the DLE anteroom.
2. All personnel don a pair of protective eyewear and disposable footgear. They then enter the DLE.
3. The operator cycles the Run/Safe box button to arm the laser. This also energizes the yellow flashing beacon in the anteroom. The operator shall then check to see that the warning beacon is illuminated (the beacon still functions while the interlock is being bypassed using the door bypass button).
4. The oscillator is turned on. Once the oscillator is emitting typical power levels, the amplifier is turned on.
5. Laser operations begin. The laser is generally operated remotely. Under normal conditions, no one is present in the DLE.
6. When the laser is functioning, personnel may enter and exit the enclosure as needed by using the magnetic lock bypass on the DLE door. The interlock and mag-lock are bypassed for 15 seconds by a keypad in the anteroom when entering the enclosure, and by a button next to the door when exiting. The door will automatically lock and the interlock will be re-enabled after this 15-second time window. Note that the outer door should remain closed when the inner door is opened and everyone in the anteroom must don LPE before the door is opened.
7. When the PSS for the accelerator is either in beam permit, or controlled access (laser), the two laser safety shutters that allow the laser beam to enter the drive laser transport system will open. Laser users shall not interfere with the functioning of these shutters.
8. Laser operations end. The laser is shut off.
9. The experimenter switches off the interlock key switch on the laser.
10. Laser eyewear is removed and stored for next operation of the laser.
11. If desired, the DLE LPSS may be crashed. Normally it is left armed.

Most maintenance on the laser itself will consist of occasional minor realignment of the oscillator and the launch into the amplifier, yearly optics cleaning and a change of the diode pump lasers every few years. These procedures are described in the User Manuals. Maintenance requiring replacement of parts should be carried out by qualified personnel following written procedures.

Laser Controls	• Describe all controls (administrative and engineering). (If a different control is recommended the rationale for not using a typical/recommended control.)

The laser is equipped with all safety features recommended by the CDRH. These safety features are described in the User manual. Copies of these sections are attached to this LOSP. In addition, the room door is interlocked and has a magnetic lock that prevents access by untrained personnel. Egress from the lab when the laser is operational is accomplished with an exit button next to the door, which bypasses the door interlock and releases the magnetic lock for 15 seconds. Entrance to the DLE is accomplished by entering a code into a keypad mounted in the entrance alcove next to the DLE door. Entering the correct code into the keypad has the same effect as pushing the exit button inside the DLE. The access code will be given only to Authorized Laser Users.

The personnel safety system (PSS) is interlocked to two shutters in the DLE. Work in the accelerator vault with the laser on is authorized when the vault has been searched and secured and when the personnel are wearing protective eyewear. See the laser safety operating procedure for the accelerator vault for a complete description of alignment of the drive laser transport.

Administrative safety procedures and training are also used to enhance safety. All laser users must be trained in laser safety. They must be familiar with this document and this document must be posted outside the lab. The laser users are responsible for not allowing non-approved personnel in the DLE. They are also responsible for wearing eye protection when a class 4 laser hazard exists. Finally, laser users shall be responsible for their own safety. They must be familiar with all warning signs, lights, and audible warnings and must know the proper safety action to take in any normal situation.

Crash buttons are provided in the DLE anteroom and in the DLE itself. The crash buttons in the DLE anteroom and the DLE shut off the laser power supply and release the magnetic lock on the door to the DLE. The crash buttons are latched so that the system stays in OPEN mode after the buttons are reset. The laser must be reset and turned back on after the crash button in the DLE is reset.

If new lasers are introduced to the lab or new procedures must be developed for new system configurations, this LSOP shall be updated and re-approved. All personnel should then be reacquainted with the procedures.

Required Calculations	• Maximum permissible exposure. • Optical density. • Nominal hazard zone.

Maximum Permissible Exposure (MPE) Levels and Certification of Required Eyewear

The class 4 laser in the DLE can put out up to 30 W of visible light and up to 70 W of invisible light.

The MPE for the doubled Nd:YVO_4 laser light, assuming a continuous laser and assuming the aversion response time of 0.25 sec. is:

$$
\begin{aligned}
\text{MPE} &= 1.8t^{3/4}\text{mJ/cm}^2 \\
&= 1.8(0.25s)^{3/4}\text{mJ/cm}^2 \\
&= 0.64\text{mJ/cm}^2
\end{aligned}
$$

If we divide by the time of exposure and multiply by the maximum aperture size of a 7 mm pupil size (0.385 cm^2) we get a power limit of 0.64*0.385/0.25=0.99 mW. For the Nd:YVO_4 fundamental light the MPE is:

$$\begin{aligned}\text{MPE} &= 9C_c t^{3/4}\text{mJ/cm}^2\\ &= 9(10s)^{3/4}\text{mJ/cm}^2\\ &= 50.6\text{mJ/cm}^2\end{aligned}$$

where C_c is the pre-retinal absorption compensation factor, which is equal to 1 for 1.064 μm. We have assumed an exposure time of 10 seconds. If we again assume an aperture size of 0.385 cm^2 and divide by the exposure time we get a maximum power incident on the eye of 1.95 mW.

For the Nd:YVO_4 we must also calculate the exposure limit for the individual pulses since it is a repetitively pulsed laser. Let us first do the calculation for full repetition rate operation for the longer oscillator (74.85 MHz repetition rate). The MPE for a green pulse with 40 psec. duration is 0.015 μJ/cm^2 times C_P where C_P is the minus fourth root of the number of pulses in the exposure time. For a 74.85 MHz laser, there are 18.713 million pulses in an exposure time. The MPE is therefore 0.23 nJ/cm^2. The irradiance limit is the repetition frequency times this value, or 17 mW/cm^2. This is much greater than the CW value of 2.56 mW/cm^2 so the CW value must be used. A similar calculation for the 1.064 μm radiation (but with an exposure time of 10 seconds) yields an MPE of 0.91 nJ/cm^2 or 68 mW/cm^2. Again, this is much greater than the CW value of 5.06 mW/cm^2 so the CW value must be used. As far as eye safety is concerned therefore, the laser is a continuous source for un-gated operation.

The advanced drive laser can be operated a lower frequency however and so one must calculate the MPE for lower frequencies as well. The MPE (irradiance limit) varies as the ¾ power of the repetition rate since the pulse energy limit varies as the -¼ power of the repetition rate but the power varies linearly with the repetition rate. If one looks at the cut-off frequency at which the pulsed and CW MPEs are the same, one finds that, for the visible, the cross-over frequency is 6 MHz. The ADL can operate as low as 0.585 MHz and the MPE for that frequency is only 0.45 mW/cm^2, far less than the CW value. For 0.585 MHz repetition rate operation, the infrared the single pulse MPE is 0.15 μ/cm^2 and the exposure time is 10 seconds. Use these numbers we find that the cross-over frequency is 2.35 MHz, which is very close to one of the available repetition rates. For 0.585 MHz the MPE corresponds to 0.69 mW. This is less than half the CW value.

In summary, we have the following maximum permissible power exposure limits for the laser. For repetition rates equal to or greater than those listed in the first two rows the CW MPE is appropriate. For lower frequencies the MPE scales down as the frequency to the ¾ power down to the value in the last two rows:

Laser and wavelength	Maximum Permissible exposure
Nd:YVO_4 @1064 nm (f≥4.678 MHz)	1.95 mW
Nd:YVO_4 @532 nm (f≥9.356 MHz)	0.99 mW
Nd:YVO_4 @1064 nm (f=0.585 MHz)	0.69 mW
Nd:YVO_4 @532 nm (f=0.585 MHz)	0.17 mW

These power levels assume that no viewing device is used to focus the beam into the eye and that no viewing of the beam is intended. In practice a machine protection system (MPS) keeps the micropulse energy less than a couple microjoules in the IR and less than 1 μJ in the visible. It physically possible, however, to get up to 30 μJ in the IR and 15 μJ in the visible if the MPS fails. These higher levels were used to calculate the required optical densities listed below.

When the power levels quoted above are used, we find that we need the following optical densities for the different wavelengths (densities are rounded up to the next higher integer):

Laser@wavelength	Power output	Optical density
Nd:YVO_4 @1064 nm (2 amp.)	25 W	5
Nd:YVO_4 @1064 nm (4 amp.)	60 W	5
Nd:YVO_4 @1064 nm (0.585 MHz, 30 μJ)	18 W	5
Nd:YVO_4 @532 nm (2 amp.)	10 W	4
Nd:YVO_4 @532 nm (4 amp.)	30 W	5
Nd:YVO_4 @532 nm (0.585 MHz, 15 μJ)	9 W	5

We have goggles with optical densities greater than 5 at both wavelengths. We may also have some prescription eyewear, which have a sandwich of KG-3 glass and OG550 glass. These also have the required densities for the Nd:YVO_4 laser.

The MPE for skin exposure in the visible is 200 mW/cm^2. The power density in the laser beam of the Nd:YVO_4 laser is approximately 3400 W/cm^2 or about 20,000 times the MPE for skin exposure. The MPE assumes a 10 second exposure. If the radiant exposure limit is used for a beam intensity of 200 W/cm^2 the time limit for an exposure is found to be much less than 1 millisecond. Since this is much shorter than the reflex time for most people, it is quite important that the user not put his or her hand in the beam. Beam enclosures shall be used wherever reasonable and care must be taken to control stray reflections from optics.

References

1. The Laser Institute of America, "American National Standard for safe use of lasers", American National Standards Institute, New York, NY (2010).

Labeling/Posting (See ES&H Manual Chapter 6410 Appendix T5 Laser Labeling/Posting Requirements	• Equipment/area labeling/posting requirements. • Area signs.

All laser ports must be labelled as a source of hazardous laser radiation. Light shields on the cable trays and other ports must be labelled. All these labels must be checked during the semi-annual certification. The door must have a "Danger" warning sign with the available lasers, their powers and wavelengths (see ANSI Z136.1 figure 1b). If a Class 3R laser is present there should be a Caution warning sign for that as well (see ANSI Z136.1 figure 1a). If maintenance work carried out by a representative from a laser manufacturer is ongoing, there must be a blue maintenance sign on the door. A green certification magnet should be on the door indicating the expiration date for the lab certification. A yellow goggle magnet should also be on the door indicating what LPE is required to enter the room.

Attachment 1

The following pages are from the Operator manuals for the drive laser. They describe the safety features of the oscillator and amplifier. Included are:

Pages 3–6 of the Time-Bandwidth User Manual for the GE-100-VAN-ETL-CLX-75/750 laser describing the safety features and safe operation procedures for the laser.

Pages 3–7 of the Q-Peak Operators Manual for the TB-MPV-532 ML 40H laser describing the safety features of the amplifier and safe operating procedures.

Attachment 2

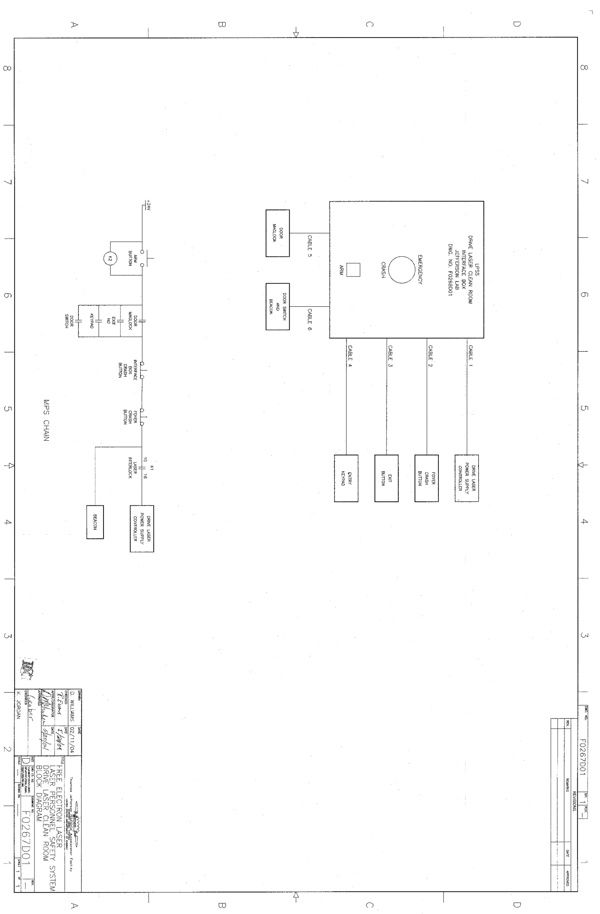
The following pages are from the Operator manuals for the drive laser. They describe the operation and alignment of the laser. Included are:

Pages 18-20,22 of the Time-Bandwidth User Manual for the GE-100-VAN-ETL-CLX-75/750 laser describing maintenance procedures and optics cleaning for the oscillator.

Note: There are no user serviceable parts to the Q-peak system.

The Aculight fiber laser manual is also included.

Attachment 3



Authorized/Trained Individuals

Print Name/Signature	Date

1.0 Revision Summary

Periodic Review – 12/22/15 – No changes per TPOC
Revision 1.1 – 07/01/14 – TechPOC changed from D. Owen to B. Manzlak.
Revision 1.0 – 12/05/10 – Updated to reflect current laboratory operations.

ISSUING AUTHORITY	TECHNICAL POINT-OF-CONTACT	APPROVAL DATE	REVIEW DATE	REV.
ESH&Q Division	Bert Manzlak	12/22/15	12/22/20	1.1

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Jefferson Lab — Thomas Jefferson National Accelerator Facility	**Task Hazard Analysis (THA) Worksheet** **(See ES&H Manual Chapter 3210 Appendix T1** **Work Planning, Control, and Authorization Procedure)**	Click For Word

Author:	Stephen	**Date:**	6/26/2017	**Task #:** If applicable	

Complete all information. Use as many sheets as necessary

Task Title:	LERF Drive laser enclosure operaton	**Task Location:**	Building 18, Rm 211

Division:	Accelerator	**Department:**	CIS	**Frequency of use:**	Indeterminate

Lead Worker:	Shukui Zhang
Mitigation already in place: **Standard Protecting Measures** **Work Control Documents**	User Lab 4 has a thoroughly commissioned and certified Laser Personnel safety system. This is effective at preventing personnel from accidentally encountering a class 4 laser. Personnel working with the laser do not get access without proper training and mentoring. Operations and procedures are carried out following an approved Laser Operational Safety Procedure.

Sequence of Task Steps	Task Steps/Potential Hazards	Consequence Level	Probability Level	Risk Code (before mitigation)	Proposed Mitigation (Required for Risk Code >2)	Safety Procedures/ Practices/Controls/Training	Risk Code (after mitigation
	Exposure to laser power in excess of threshold damage limits	M	M	3	Laser Personnel safety system and user of Laser safety eyewear and lab coats.	Training on the LOSP for this lab.	1
	Fire Hazard from class 4 laser exposure	M	M	3	Eliminate flammables from laser use. LPSS smoke alarm in the clean hood will shut off laser.	Procedures and LPSS system certification spelled out in the LOSP for this lab.	1

Highest Risk Code before Mitigation:	3	**Highest Risk Code after Mitigation:**	1

When completed, if the analysis indicates that the Risk Code before mitigation for any steps is “medium” or higher (RC≥3), then a formal Work Control Document (WCD) is developed for the task. Attach this completed Task Hazard Analysis Worksheet. Have the package reviewed and approved prior to beginning work. (See ES&H Manual Chapter 3310 Operational Safety Procedure Program.)

Form Revision Summary

Periodic Review – 08/13/15 – No changes per TPOC
Revision 0.1 – 06/19/12 - Triennial Review. Update to format.
Revision 0.0 – 10/05/09 – Written to document current laboratory operational procedure.

ISSUING AUTHORITY	TECHNICAL POINT-OF-CONTACT	APPROVAL DATE	REVIEW DATE	REV.
ESH&Q Division	Harry Fanning	08/13/15	08/13/18	0.1

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By signing this page, you testify that you have read, understand, and agree to abide by the procedure specified in the above referenced work control document:

Serial Number: ACC-17-69180-LOSP

Title: LERF Drive Laser Enclosure

Name	**Signature**	**Date**