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Jefferson Lab — Thomas Jefferson National Accelerator Facility

Operational Safety Procedure Review and Approval Form # 84845
(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-19-84845-LOSP***
Issue Date:	***6/5/2019***
Expiration Date:	***5/5/2022***
Title:	***Drive Laser Alignment in the LERF Vau***
Location: (where work is being performed) Building Floor Plans	***18 - Low Energy Recirculator Facility (LERF) - 107*** — Location Detail: (specifics about where in the selected location(s) the work is being performed): ***Injector pit***
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

Supplemental Technical Validations

Lasers Class 3B or 4 (Ultraviolet, Infrared, and Visible Light)   (Bert Manzlak, Jennifer Williams)
Lock, Tag, Try   (Paul Powers, Todd Kujawa)
Fire Protection   (Tim Minga)

Document History

Revision	Reason for revision or update	Serial number of superseded document

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

Attachments

Procedure: ***LSOP, New Drive laser in vault-r5.pdf***

THA: ***THA for vault alignment.pdf***

Additional Files:

Review Signatures	
Additional Authorization : Fire Protection - other than current engineered safeguards or fire watch	**Signed** on 5/15/2019 2:28:12 PM by Tim Minga (minga@jlab.org)
Subject Matter Expert : Lasers Class 3B or 4 (Ultraviolet-> Infrared-> and Visible Light)	**Signed** on 5/31/2019 10:49:16 AM by Bert Manzlak (manzlak@jlab.org)
Subject Matter Expert : Lock-> Tag-> Try	**Signed** on 4/18/2019 2:34:37 PM by Todd Kujawa (kujawa@jlab.org)

Approval Signatures	
Division Safety Officer : ACCASA	**Signed** on 5/31/2019 11:07:53 AM by Harry Fanning (fanning@jlab.org)
Org Manager : ACCASA	**Signed** on 6/3/2019 11:53:17 AM by Todd Satogata (satogata@jlab.org)
Safety Warden : Low Energy Recirculator Facility (LERF) - 107	**Signed** on 6/5/2019 6:33:33 AM by Kevin Banks (banks@jlab.org)
Subject Matter Expert : Lasers Class 3B or 4 (Ultraviolet-> Infrared-> and Visible Light)	**Signed** on 5/31/2019 10:50:45 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:	**Drive Laser Alignment in the LERF Vault**		
Location:	Building 18 (LERF) Room No. 107		
Description of Project	Alignment of Drive laser onto the Injector gun cathode before beam operations under control of the Personnel Safety System.		
Document Owner(s):	Stephen Benson	**Date:**	4/3/2019

Laser Inventory

	Laser Serial #	Laser Class	Wavelength(s)	Maximum Power/Energy
1.	2599-1	4	0.53 μm	30W
2.				

Approval Signatures:	Print	Signature	Date:
Laser System Supervisor:	Benson, Stephen (felman@jlab.org)		
Laser Safety Officer:	Bert Manzlak		
Division Safety Officer	Harry Fanning		
Department or Group Head:			
Other Approval(s):			

Document History:

Revision:	Reason for revision or update:	Serial number of superseded document
	Old version expired.	ACC-16-58485-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.

A class IV laser is used to drive the photocathode gun for the driver accelerator in the Low Energy Recirculation Facility (LERF, or building 18). When the accelerator is not being operated, the laser beam is contained in the drive laser enclosure (DLE). The safety of this facility is covered in a separate Laser Operations Safety Procedure (LOSP) [ref. # ACC-17-69180-LOSP]. During operation of the accelerator, the accelerator vault is off limits to personnel. The personnel safety system (PSS) ensures that no one is in the vault when the gun is operated. The hazard to Jefferson Lab employees is then minimized by use of the PSS. During alignment of the drive laser however some Jefferson Lab personnel are exposed to a laser hazard that may be as large as class IV. This LOSP gives a description of the laser used, the hazards present, a description of the laser enclosure and the procedures for safe operation during drive laser alignment.

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.

Personnel performing drive laser alignment in the LERF vault must have completed the EH&S Orientation to Jefferson Lab (SAF100), Radiological Worker Training I (SAF801F), SAF143kd LERF Safety Awareness training, and Oxygen Deficiency Hazards Training (ODH, which is SAF103). They must also satisfy the following requirements before doing any work in the vault when it is in LASER PERMIT CONTROLLED ACCESS:

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 need not be repeated on a regular basis but 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/6410.htm

3. Take a laser safety course administered by the Jefferson Lab Laser Safety Officer (LSO) (SAF114O).
4. Read this document.
5. Have a safety walk-through of the DLE carried out by the laser system supervisor (LSS) for the LERF (now Steve Benson, the course is SAF115DLE).

A list of qualified laser personnel is available in the MCC and can be requested from the Crew Chief.
Only personnel qualified for the DLE may be in the LERF vault when it is in LASER PERMIT CONTROLLED ACCESS. The Jefferson Lab Laser Safety Officer (LSO) for the lab may grant exceptions to this rule in special circumstances. Other Jefferson Lab personnel or outside visitors may enter the vault only when it is in RESTRICTED ACCESS or normal CONTROLLED ACCESS. Visitors to the LERF vault must be accompanied at all times by someone with ODH and GERT or better training and must have an SRPD personnel dosimeter from the Radiation Control Group.

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

There is presently one laser used in the accelerator vault that qualifies as a class IV laser hazard. It is a frequency doubled IR laser amplifier that is driven by an IR oscillator laser. Only the frequency doubled light is sent downstairs. A description of the laser amplifier follows. The parameters are listed in Table 1.

Notes: The Drive laser may be mode-locked 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 25 W of infrared light with two amplifiers and 70 W of infrared light with four amplifier stages. The 25 W beam exits the laser enclosure before being doubled in a crystal. The 70 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. 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 the "Required Calculations" section). The MPE is smaller for an assumption of pulsed operation for frequency less than 2.5 MHz in the green. The oscillator laser system consists of a mode-locked oscillator with a diode pumped Nd:YVO_4 chip as its gain medium and passive SESAM mode-locking. An electro-optic controller for modifying the pulse structure follows, then 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 laser beam. The laser has all safety features necessary under CDRH guidelines[1]. See the attachments to ACC-17-69180-LOSP for a description of safety features and safety labels. This frequency doubled laser light is sent to the vault through a stainless steel transport assembly structure. Only the green light can make it to the vault due to the mirror reflectivity curves in the optical transport.

Table 1. Parameters for Injector Drive Laser Beam

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 number	2599-1
Wavelength 1	1.06 µm
Power at Wavelength 1 (2 amps)	30 W
Power at Wavelength 1 (4 amps)	60 W
Wavelength 2	0.53 µm
Power at wavelength 2 (2 amps)	10 W
Power at wavelength 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)

The only other lasers used in the vault are Class 3R lasers. They are used for alignment and for quantum efficiency measurements on the cathode. The green He-Ne laser on the light box is normally blocked but may be uncovered during an access.

[1] See ANSI Z136.1-2007 Section 4.3 for description of necessary engineering controls on Class 3 and 4 lasers.

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 clear 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 always emits an infrared beam that is usually not sufficiently powerful to burn skin (<10 mW). This infrared beam is strongly attenuated by the optical transport so that it is class 1 in the vault. 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. Appropriate laser safety eyewear is available in the anteroom of the DLE. Note that the laser is remote controlled so turning off the laser does not ensure safety. The key on the column next to the electron gun must be removed, or the vault must be brought out of LASER PERMIT/CONTROLLED ACCESS before one may remove his or her laser safety eyewear. The best way to reduce the burn hazard is to align with the lowest power usable, using fluorescent cards to locate the beam. When aligning with high power, it is necessary to know where the laser beam travels before working with it.

Lighting in the accelerator vault is similar to office lighting under normal circumstances but a fully dilated pupil (7 mm diameter) is used for calculating the laser hazard since the laser user may find it necessary to align the laser with the lights off.

Nominal Hazard Zones

To illustrate the laser hazard more fully it is useful to calculate the nominal hazard zone 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 Table 2 we show the calculated Nominal Hazard Zone (NHZ) radii for specular and diffuse reflections for the various lasers the LERF vault. For the diffuse reflection we assumed a worst-case albedo of unity and a worst-case angle of 0°.

Table 2, 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)
ADL (4 Amps)	1750	276	0.44	0.069

The nominal hazard zone for this laser 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 as good as a hit for this laser. This is why laser safety eyewear is mandatory.

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 enters the vault via an optical transport line. Work on this transport line when the vault is not in CONTROLLED ACCESS LASER PERMIT requires lock, tag, and try on the laser. Either the machine protection shutter or the drive laser electrical plug must be locked out and the personnel doing the work must verify using an imaging card 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 the LERF 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 certified for use with the ADL is listed in Table 3. Laser safety eyewear with an optical density (O.D.) 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 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.

Table 3. 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 @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, 5 μJ)	2.93 W	5

Pay careful attention to the laser safety eyewear selection. The appropriate laser safety eyewear should have at least an optical density of 5 at 532 nm. It is a very good idea to read the label on the laser safety eyewear to make sure that they match this requirement.

Non-beam hazards

The non-beam hazards due to the laser, in order of their likelihood: are fire, electrical shock, and burns.
It is not possible to access any of the drive laser electronics from the vault. No work on any electronic systems should be done when in controlled access laser permit.
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 extinguisher in the injector pit and the evacuation route (see figure 1).

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 injector pit of the accelerator vault. The laser light is transported from the drive laser enclosure (DLE) to the accelerator vault through a metal transport line (see figure 1). The light reflects off two mirrors before going through a telescope box that images an aperture in the DLE onto the photocathode. After the telescope, the light then reflects off two more mirrors before passing along the light box rail, off two more periscope mirrors and into the vacuum chamber of the light box. The light reflected off the cathode is directed out of the vacuum chamber and onto a beam dump. Part of the beam is picked off for laser phase monitoring. During laser alignment, the transport line may be brought to atmospheric pressure and opened, exposing the user to the class IV laser. Even when the transport line is secure, the laser light travels through air between the exit vacuum window of the transport line and the entrance window of the light box as well as between the exit window of the light box and the beam dump. These spaces are normally enclosed in opaque covers when in use.
The shutters that allow the drive laser light to enter the transport line are controlled by the PSS. Under most circumstances one of two situations is present; 1) The PSS laser shutters are closed, the optical transport line is intact and the light box rails are covered with a sintra beamline cover, and the accelerator vault is accessible by personnel. 2) The PSS laser shutter is open and the accelerator vault is searched and secured and placed in a BEAM PERMIT state so that no-one is present in the vault. In these two situations there is no hazard to personnel or visitors except in the DLE, which is covered by a separate LOSP. This LOSP covers a third situation—the laser shutter is opened using a bypass key during a CONTROLLED ACCESS and the laser is aligned onto the laser cathode. A fourth situation is when work is being done on the optical transport line and the drive laser operator shutter or drive laser is locked out using LTT. This is similar to situation 1.
The non-laser hazards are listed in section 4 of this LOSP. When alignment is being done, the laser user may be using a ladder or raised platform. Ladder and platform safety procedures must be followed.
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 building smoke detectors activate an alarm signal in the FACP that will sound the building audible alarms. The building audible and visual alarms sound when smoke in the area exceeds the trip level of the building smoke detectors. These 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 LERF or 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 emergency responders.
A portable fire extinguisher near the roll-up door. It is class C and can be used to extinguish small fires.

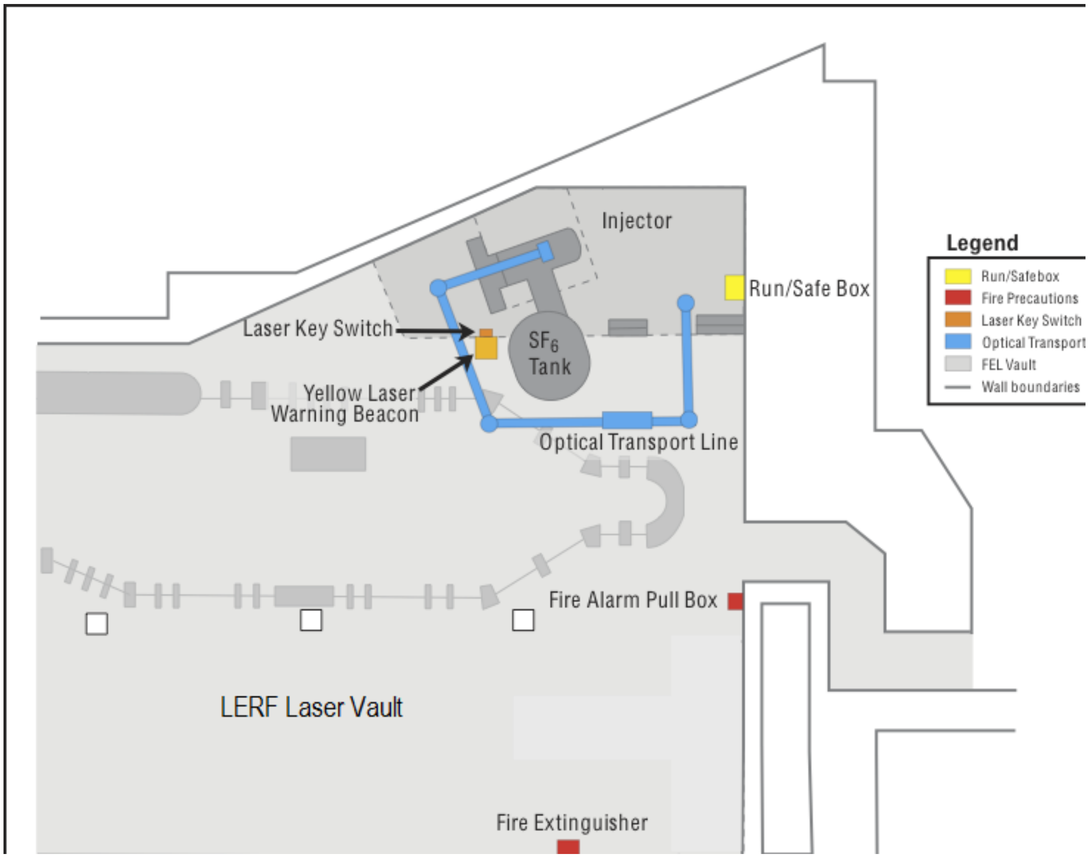

Figure 1. a) Layout of LERF accelerator vault. Locations of the fire extinguisher, laser key switch, and Run/Safe boxes are shown. The drive laser enters through the ceiling near the run/safe box and is transported to the light box just downstream of the gun. The alignment work occurs next to the light box.

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).

Every six months or any time when the PSS undergoes maintenance, the PSS shall be audited. The procedure for the PSS audit is maintained by the Safety Systems Group. A record of the latest certification dates for the vault can be obtained by contacting the Jefferson Lab Safety System Group.

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 vault, the nearest fire alarm pull box should first be pulled to start a building evacuation. If the fire is small enough, a fire extinguisher in the vault 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 or conditions rapidly deteriorate, the user should immediately leave the vault. If the fire alarm sounds due to a fire upstairs, all personnel must immediately evacuate the building. In the event of a building fire alarm, the laser user should crash the vault to RESTRICTED ACCESS by crashing one of the PSS boxes in the vault. The user should then exit the building and gather at the muster point (just outside the main door). The operator should then dial 911 from a landline phone and report the fire.

In the event of a building ODH alarm the user must exit the building. 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 a laser beam 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 from a landline phone. If calling from a cell phone, call 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 an ophthalmologist subsequently examines the victim.
4. After the victim recovers from the acute injury, Occupational Medicine will provide her/him with a letter explaining the injury.
5. The LSO and LSS 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 from a landline phone. If calling from a cell phone, dial 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 them 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 and LSS 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:

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 vault to authorized personnel only. No multi-tasking is allowed!
3. Consider the need for additional personnel during alignment. It may go much 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. Laser Protective Eyewear shall be worn at all times during the alignment.

2. There shall be no intentional intrabeam viewing with the eye. If intrabeam viewing is required, use an imaging device such as a camera, imaging plate, or cell phone.
3. Reduce the beam power using either the repetition rate, duty cycle or drive laser attenuator. Avoid the use of high-power settings during alignment as much as is practical. Most alignment can be carried out with no more than 100 mW of average power.
4. Keep the laser beam under control. Close the shutter when moving optics. This takes a bit longer but pays off in results and safety.
5. Terminate stray or unused beams.
6. Use fluorescent cards or a camera to view the laser beam. Lower power can then be used. The pick-off beam from the Brewster window on the optical transport system is very weak and must be viewed using a beam viewer (a cell phone can work as well).
7. Remember to replace the light box rail shroud after alignment is done.

Typical Alignment Procedure:

Normal alignment of the lasers should follow this procedure. It is worth repeating that most alignment can be carried out with less than 100 milliwatts of laser light. Only rarely must one align at full power. The users should use the smallest usable power to align the transport line:

1. At least one hour before starting the alignment, the approved laser user must contact the Crew Chief (x7045) and SSO (x7050) and inform them that you will be shortly going to CONTROLLED ACCESS/LASER PERMIT. The SSO and Crew Chief must then review the guidelines for access to the vault in this mode.
2. The approved laser user must get the laser bypass key from the key control box in the MCC. This allows one to put the vault into CONTROLLED ACCESS/LASER PERMIT. At this time, the approved user must make sure that the SSO and Crew Chief are prepared to properly monitor access to the vault.
3. The accelerator vault must be in a CONTROLLED ACCESS mode with all keys in the key bank before alignment can begin. If necessary, sweep the vault and put it into CONTROLLED ACCESS. If the vault is already in CONTROLLED ACCESS, make sure that all keys are in the key bank and that the pass key is in the upper box.
4. Authorized laser users get protective eyewear (available in the DLE anteroom) and check it for cracks or scratches. While in the anteroom, the users must activate the laser bypass key, which allows the laser shutter to open. This action illuminates flashing yellow beacons in the accelerator vault and in the anteroom and starts an audible warning that a class IV laser hazard will be present in 30 seconds as soon as the CONTROLLED ACCESS pass key is removed (this will only happen if the system is in CONTROLLED ACCESS or power permit). It also activates an indicator in the MCC to indicate that the laser shutter is bypassed.
5. The laser user or users then go downstairs and contact the MCC to gain access to the accelerator vault anteroom.
6. The user or users then get a CONTROLLED ACCESS key and, using the closed circuit TV, show their radiation badges, keys, and goggles to the SSO in the MCC so that they can enter the vault. If they have all of these, are ODH trained, and are on the approved user list, they can enter the accelerator vault.
7. The SSO permits the users in the vault and then re-energizes the maglocks. Anyone else wanting to enter at this point must go through the same procedure to enter.
8. During laser alignment, the laser user may close the operator shutter using a key-switch in the injector pit. The PSS shutter remains open. This must not be used as a substitute for the PSS shutter.
9. If someone who is not an approved laser user needs to enter the vault during the alignment, the laser user must exit the vault and close the PSS shutter using the laser bypass key in the DLE anteroom before the other person enters the vault. Alternatively, the system may be dropped to RESTRICTED ACCESS if a radiation survey has been completed.
10. The typical laser alignment consists of verifying that the laser is centered in the transport line telescope (this is usually done using the Fresnel patter on the Brewster window camera), and then adjusting the position of the second lens of the telescope and the angle of the last mirror of the transport line so that the beam is centered in the entrance aperture of the light box rail. The position of the beam on the cathode can be monitored using the light box camera. The two mirrors on the light box rail are used to center the beam on the cathode and in the light box aperture.
11. When the alignment is complete, the laser users reinstall the sintra shroud around the light box rails and request permission to leave the vault from the MCC operator. When it is granted, they enter the anteroom and return their keys to the key banks. The laser bypass key in the DLE anteroom is then switched to normal mode and returned to the MCC. If the personnel doing the alignment take an extended break, they should remove the laser bypass key so that other personnel may enter the vault under normal CONTROLLED ACCESS.

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

Though the drive laser is equipped with all safety features recommended by the CDRH, these are not accessible when the laser user is in the accelerator vault. CDRH and ANSI guidelines were used in the design of the PSS for the accelerator vault.

1. The accelerator vault has magnetic locks that limit access to approved personnel. If entry or egress to the lab is required when the laser shutter is open, the MCC operator must allow the person to pass through the doors at either end of the entry alcove and must check that they are wearing laser goggles (see ANSI 4.3.1.2 and 4.3.10.2 option 2).
2. The vault has interlocks on all access points that will close the laser shutter if tripped (ANSI 4.3.10.2 option 2). If an access point is violated, the PSS drops to RESTRICTED ACCESS and the PSS shutters close.
3. A bypass key must be activated before the safety shutter is opened (see ANSI 4.3.4).
4. Before the laser shutter opens, yellow flashing beacons are illuminated in the vault and the alcove and a warning is played over the PA system (ANSI 4.3.9). Thirty seconds after the safety system is activated, the PSS shutters open (ANSI 4.3.9.1).
5. There shall be warning signs in the alcove and in the vault, which clearly state that a class IV laser hazard exists when the yellow flashing beacons are on and that appropriate laser goggles are then required (ANSI 4.3.10.2).
6. Crash buttons in the vault and the alcove are provided so that the PSS system may be deactivated at any time if rapid egress is required (ANSI 4.3.10.2). The crash buttons cause the PSS to return to a restricted access mode, which closes the laser shutter and releases the magnetic locks on the doors to the vault. All crash buttons must be reset manually after being pushed. The vault must be re-swept and secured before the laser shutter can be opened again.

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 in the LERF facility. The laser users and the MCC operators are responsible for not allowing non-approved personnel in the accelerator vault during alignment. They are also responsible for wearing eye protection when a class IV 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.

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

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 infrared light is not sent into the drive laser transport and there are losses in the transport of the light to the transport line so that the average power in the transport line is typically much less than 20 Watts. The typical laser power at the laser exit is used in these calculations.

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 CP where CP 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.
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	Max. Power exp.
Nd:YVO_4 @532 nm (f≥9.356 MHz)	0.99 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 1 µJ in the visible. It physically possible, however, to get up to 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 in the laser description are used, we find that we need the following optical densities for the different wavelengths:

Laser@wavelength	Power output	Optical density
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, 5 µJ)	2.9 W	5

The DLE laser protective eyewear has optical densities greater than 5 at 532 nm. We may also have some prescription eyewear, which have a sandwich of KG-3 glass and OG550 glass. These 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 can be as high as 3000 W/cm2 or about 15000 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 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. Alignment using a reduced-power beam is also an effective way to reduce the skin hazard.

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

There shall be warning signs in the alcove and in the vault, which clearly state that a class IV laser hazard exists when the yellow flashing beacons are on and that appropriate laser goggles are then required

Authorized/Trained Individuals

Print Name/Signature	Date

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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Task Hazard Analysis (THA) Worksheet

(See ES&H Manual Chapter 3210 Appendix T1
Work Planning, Control, and Authorization Procedure)

Click For Word

Author:	Stephen Benson	**Date:**	4/18/2019	**Task #:** If applicable	

Complete all information. Use as many sheets as necessary

Task Title:	Drive laser alignment in the LERF vault			**Task Location:**	Building 18, room 107
Division:	Accelerator	**Department:**	CASA,CIS	**Frequency of use:**	~Twice yearly
Lead Worker:	Shukui Zhang				

Mitigation already in place: Standard Protecting Measures Work Control Documents	The LERF vault has a thoroughly commissioned and certified Personnel safety system. This prevents personnel from accidentally encountering a class 4 laser. Optical transport shields also prevent exposure. Controlled Access/Laser Permit is not allowed without Crew Chief permission. Personnel working with the laser do not get access without proper training. 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	Personnel Safety System and user of Laser safety eyewear, Alignment at low power when possible.	Laser safety training and LOSP.	1
	Fire Hazard from class 4 laser exposure	M	M	3	User low power during alignment and keep flammables away from the beam.	Procedures and PSS system certification spelled out in the LOSP	

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 – 08/29/18 – No changes per TPOC
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	08/29/18	08/29/21	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-19-84845-LOSP

Title: Drive Laser Alignment in the LERF Vau

Name	Signature	Date