1. Introduction

Room 206A of the Free-electron laser Facility at Jefferson Lab (hereafter referred to as the Drive Laser Enclosure, or DLE) contains a Class IV laser[1] which drives the IR Demo injector photocathode (see figure 1). Laser hazards are present both in the DLE and in the accelerator enclosure. This Laser Standard Operating Procedure (LSOP) gives a description of the laser used, the hazards present, a description of the laser enclosure and the procedures for safe operation. Procedures for entering the accelerator vault for laser transport alignment are given in a separate LSOP.

2. Personnel

All personnel working in experimental areas at Jefferson Lab must have completed the EH&S Orientation at Jefferson Lab.

All users of the laser shall 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 employee's time at Jefferson Lab and must be completed before the users operate any class IIIb or class IV lasers.

When working with the laser, the users must not wear any jewelry or clothing which presents a specular reflection hazard.

Other Jefferson Lab personnel or outside visitors may only enter the DLE while the laser is off or when the laser is operating and all beam paths are enclosed (i.e. only class I laser hazards are present) as long as they are accompanied by one of the approved users. Long term visitors may work in the DLE with Class IV laser hazards if they have successfully completed all the training required of Jefferson Lab personnel for working in the DLE and have fulfilled all medical requirements.

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[1]See ANSI Z136.1-1993 Section 3.3 or section 6410 of the CEBAF EH&S manual for classification of laser hazards.

3. Lasers in the Drive Laser Enclosure

There is presently one laser in the drive laser enclosure which qualifies as a class IV laser. A description follows,

Laser #1

Type of laser	Frequency doubled mode-locked Nd:YLF
Manufacturer	Coherent, Inc.
	5100 Patrick Henry Drive
	Santa Clara, CA 95054 (800)367-7890
Model	Antares 76-YLF
Serial numbers	93280669, 93290077
Wavelength 1	1053 nm
Wavelength 2	527 nm
Power at Wavelength 1	15 W
Power at Wavelength 2	~6 W
Pulse width(wl #2)	40 psec FWHM
Pulse rate	74.85 MHz
Beam diameter	1.5 mm
Beam divergence	0.5 mrad

Notes: This laser is modelocked at 74.85 MHz and emits 35–45 psec. pulses with up to 80 nJ of energy in the green. The laser also emits up to 20 W of infrared light. This may be emitted outside the cavity occasionally. (*e.g.*, when the laser is undergoing a major optics realignment or for diagnostic purposes.) A dichroic filter usually stops 99.5% of this power inside the laser head so that the normal infrared output power is less than 100 mW. A diagnostic port allows approximately 100 mW of infrared light to escape from the high reflection mirror for monitoring. Since the pulses occur at such a high frequency, the light output is continuous as far as eye safety is concerned. The laser system consists of an optical cavity, an acousto-optic modelocker, a laser gain module, a safety shutter, an internal power monitor, a doubling crystal, the dichroic beam splitter, a power supply for the laser head, control electronics for the doubling system and the acousto-optic modelocker, three fast electro-optic cells for gating the laser beam, and a set of diagnostics for characterizing the beam. The laser cover is interlocked to prevent operation with the cover open. Maintenance procedures requiring an open cover are discussed in the Coherent manual. The manual should be read thoroughly before performing these procedures. The laser has all safety features necessary under CDRH guidelines[2]. See the attachments to this document for a description of safety features and safety labels.

The only other lasers used in the lab are Class IIIa helium-neon lasers. They are used for alignment.

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[2] See ANSI Z136.1-1993 Section 4.3 for description of necessary engineering controls on Class III and IV lasers.

4. Hazards

The Antares 76-YLF 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 doubled Nd:YLF beam to be seen dimly so that one knows where the beam is when wearing goggles. 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 emits an infrared beam which is not sufficiently powerful to burn skin. This beam is present at all times but is confined to a small area outside the laser head. At times the laser emits a high power beam which can cause serious deep tissue burns. Great care must be exercised when working with the infrared high-power beam. Since it cannot be seen, it is imperative that goggles be worn at all times when working with this laser. The best way to ensure that no harm comes to the user's eyes is to wear appropriate safety goggles at all times when working with a laser. Appropriate goggles and glasses are available in the anteroom of the DLE.

Eventually, once the laser is tuned up, aligned, and debugged, its beamlines may be enclosed by interlocked non-flammable covers opaque to the laser radiation. When all the beamlines are enclosed the hazard is reduced to that of a Class I laser. If the Laser System Supervisor inspects the laser beamlines and determines that any stray light getting out of the enclosure presents no more than a Class I laser hazard, the laser users may remove their goggles and visitors may enter the lab if accompanied by an approved laser user. Unless the beamline cover interlocks have been certified by the Laser system supervisor, the user shall always wear goggles when using the laser system.

The non-beam hazards due to the laser, in order of their likelihood, are high voltage, fire, toxic gas release, burns, and steam explosions.

Under normal operation there are no exposed voltages in the laser. It is important to follow the safety instructions of the manuals. Work on electronic parts of the laser shall be done only by qualified service technicians. Interlocks on the power supply doors and covers shall not be defeated by Jefferson Lab personnel. Lethal voltages and currents are exposed in the laser power supply when the door is open. The power supply doors shall remain closed whenever the laser power supply is plugged in unless being worked on by a service technician, or during a test or maintenance of the interlock. During maintenance of the interlock the power supply should be shut off.

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.

If the laser heats or burns some materials (e.g. Plexiglas) toxic gasses could be released. This can best be prevented by being careful about what materials the laser encounters.

There are hot components in the laser head, even after the laser is turned off. Caution should be exercised when working around the doubling crystal (it is in an insulated oven but it has very little insulation), the acousto-optic modulator in the Nd:YLF laser, or with the laser head itself (which is normally well-cooled by the water system). There are several laser beam dumps as well which can get very hot if they are operated without water cooling (several are air-cooled).

There is a very small risk of the laser head having a steam explosion if there is an interruption in the water coolant. There are interlocks to keep this from happening. They should be checked every six months to make sure they are operational. Any explosion should be contained by the laser head cover. Since the user must always wear goggles or glasses when working on the laser with the cover removed, the user's eyes should also be protected from the steam explosion if the cover is removed, but the user could suffer other injuries.

5. The laser environment

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 IR Demo driver accelerator. The laser light is transported from the DLE to the accelerator vault through an evacuated metal transport line (see figure 1).

The DLE is a controlled area during laser operations and the laser is interlocked to the room safety system. The laser is also interlocked by a key on its remote interface control. During laser operations only authorized users will be allowed in the room unless the beamlines are enclosed and certified by the laser system supervisor to be a class I hazard. 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.

The DLE has only one entry and exit point. The integrity of the lab must be maintained. To ensure this, a magnetic lock will secure 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 another door. If the interlock has been energized, entry is permitted by bypassing the interlock, either by (1) entering the proper four digit code into the keypad, or (2) requesting a user already in the DLE to temporarily bypass the interlock.

The lighting in the DLE shall be typical of office lighting under typical operating conditions. 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).

There are no non-laser hazards in the DLE. Hazardous voltages are present inside some of the electronic components in the DLE. Work on these components must be done by qualified service personnel only.

6. Procedures

Every six months or any time when the laser undergoes maintenance, the laser shall have its safety interlocks checked. The following checks must be carried out and documented (items 1 and 11 need not be done after maintenance):

1) Make sure all warning signs are in place.
2) Verify that the laser cannot be turned on without the key.
3) Check to see that the laser cannot operate with the Run/Safe box on Safe. Make sure that opening the door to the room shuts off the laser unless the door bypass button is pushed.
4) Make sure the power supply door interlocks turn off the electrical power to the laser head when the supply door is opened.
5) Make sure the interlock on the laser head cover turns off the power for the laser when the cover is opened.
6) Verify that removal of remote interlock plug from the laser causes the laser to shut off.
7) Verify that the laser emission indicators are illuminated on both the control panel and the laser head when the lamp currents are turned on.
8) Verify using a low level power meter that the laser safety shutter reduces laser emissions to class I levels.
9) Verify that the laser must be reset manually when any interlock is tripped.
10. Verify that shutting off the secondary water shuts off the power supply. This is best done by disconnecting the flow interlock.
11) Make sure that at least one of the power meters used for power monitoring is calibrated. The other power meters can then be checked against the calibrated unit.
12) Inspect the laser safety eyewear for integrety and proper wavelength range. Protection level must be at least as good as the LSOP requires.

Every month the fire extinguisher should be checked and documented. In addition, the safety eyewear should be checked for any damage which would compromise their integrity.

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

1) Authorized personnel enter the DLE anteroom.
2) All personnel get a pair of protective eyewear and disposable footgear. They then enter the DLE.
3) After checking the status of the modelocker driver and SHG controller, the laser user enables the laser chiller using the wall mounted disconnect.
4) The laser user secures the key interlock in the laser remote control panel.
5) The laser power supply disconnect switch is energized.
6) All room interlocks are closed and verified.
7) The operator cycles the Run/Safe box button to arm the laser. This also energizes the sign outside the laboratory. The operator shall then check to see that the warning sign is illuminated (the sign still functions while the interlock is being bypassed using the door bypass button).
8) All personnel in the room shall don appropriate eye protection.
9) The laser user turns the key in the laser Remote Interface Control and turns on the laser.
10) The experiment begins. The laser power may be optimized by controls on the laser and the laser power incident on the target may be adjusted via a variable attenuator.
11) If interlocked beamline covers are in place, they shall be checked by the laser users to verify that they are all in place and that the beamline cover interlock is functional. If this is the case the personnel may remove their eye protection. Otherwise, the personnel in the lab must wear eye protection as long as the laser is on.
12) When the laser is functioning, personnel may come and go as needed using the magnetic lock bypass on the DLE door.
13) When the PSS for the accelerator is either in POWER PERMIT, BEAM PERMIT, or CONTROLLED ACCESS (LASER), the laser safety shutters which allows the laser beam to enter the drive laser transport system will open. Laser users shall not interfere with the functioning of these shutters.
13) Laser operations end. The laser is shut off.
14) The interlock key switch on the laser is switched off by the experimenter.
15) Laser eyewear is removed and stored for next operation of the laser.
16) The interlock chain is broken and Run/Safe box secured by the operator.

Most maintenance on the laser itself will consist of laser lamp replacement, occasional realignment, and optics cleaning. These procedures are described in the operators manuals. Copies of these procedures are attached to this LSOP. Maintenance requiring replacement of parts (other than lamps) should be carried out by service personnel from Coherent, Inc.

Occasionally, the laser beam path on the optical bench must be realigned. Minor alignment of the beam transport can be carried out at higher power but alignment of the class IV laser at full power is strongly discouraged since alignment targets cannot withstand the full beam intensity without shattering or burning. Under some conditions the attenuation of the delivery system is quite high and the power at the point of alignment may be very low. In this case the Laser System Supervisor may authorize alignment without protective eyewear if it is determined that the maximum laser power out of the laser is less than 1 mW and there is no invisible radiation. Minor alignment carried out with the laser power higher than 1 mW must be carried out with goggles at all times.

Service of the laser will normally be carried out by qualified service representatives from Coherent, Inc. The only service required on the laser under normal operation by Jefferson Lab personnel is the replacement of lamps and optics cleaning. This is to be done as described in the operator manual. The LSS is responsible for verifying that appropriate Jefferson Lab Lock and Tag Procedures are followed when warranted.

In the event of an accidental eye exposure or of a skin exposure causing a burn, the user must first contact the medical services (either a local emergency room or the Jefferson Lab clinic) to seek medical attention and then must contact the laser system supervisor to report the incident as soon as possible after receiving medical attention.

In the event of fire in the DLE, the power for the laser can be disconnected using the wall mounted disconnect and can then be extinguished using the fire extinguisher in the lab. If the fire cannot be extinguished in this manner the user should leave the room, call 911, and pull the nearest fire alarm box.

7. Laser controls:

The laser is equipped with all safety features recommended by the CDRH. These safety features are described in the operators manual. Copies of these sections are attached to this LSOP. In addition, the room has a magnetic lock that forbids access to untrained personnel. If egress to the lab is required when the laser is operational, a push button next to the door can be momentarily depressed and the door opened for about 20 sec. without breaking the interlock chain. Entrance to the DLE is also allowed by entering a four digit code into a keypad that is mounted next to the DLE door. This code will be given only to authorized laser users. Interlocked beamline covers may be used to reduce the hazard to that of a Class I laser. These covers are in addition to the room safety system. The personnal 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 (unless the Laser System Supervisor has given permission to align at low power without goggles). 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 in 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 IV laser hazard exists (beamline covers can reduce the laser hazards to those of a class I laser). 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. All crash buttons must be reset manually after being pushed. They are also 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.

Interlocked beamline covers may be used to reduce the laser hazard in the DLE to a Class I hazard. The beamline covers must inspected by Laser System supervisor when they are installed, and whenever changes are made to them or the interlocks. Whenever the beamline cover interlock is bypassed there should be a clear indication to the laser user that a class IV laser hazard may exist. A hazard warning sign should be posted at the entrance to the DLE and the Injector Cave.

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

7.1 Maximum Permissible Exposure levels:

The class IV laser in the Injector Test Stand can put out up to 8 W of visible light and up to 20 W of invisible light.

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

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

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:YLF fundamental light the MPE is:

$$MPE = 9C_c t^{3/4} mJ/cm^2$$
$$= 9(10s)^{3/4} mJ/cm^2$$
$$= 50.6 mJ/cm^2$$

where C_c is the pre-retinal absorption compensation factor which is equal to 1 for 1.053 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:YLF we must also calculate the exposure limit for the individual pulses since it is a repetitively pulsed laser. The MPE for a green pulse with 40 psec. duration is 0.5 $\mu J/cm^2$ 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 7.6 nJ/cm^2. The irradiance limit is the repetition frequency times this value, or 0.57 W/cm^2. This is far greater than the CW value of 2.56 mW/cm^2 so the CW value must be used. A similar calculation for the 1.053 μm radiation gives an MPE of 3 nJ/cm^2 or 225 mW/cm^2. Again, this is far greater than the CW value. As far as eye safety is concerned therefore, the laser is a continuous source.

In summary, we have the following maximum permissible power exposure limits for the laser:

Laser and wavelength	Max. Power exp.
Nd:YLF @1053 nm	1.95 mW
Nd:YLF @527 nm	0.99 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.

When the power levels quoted in the laser description are used we find that we need the following optical densities for the different wavelengths:

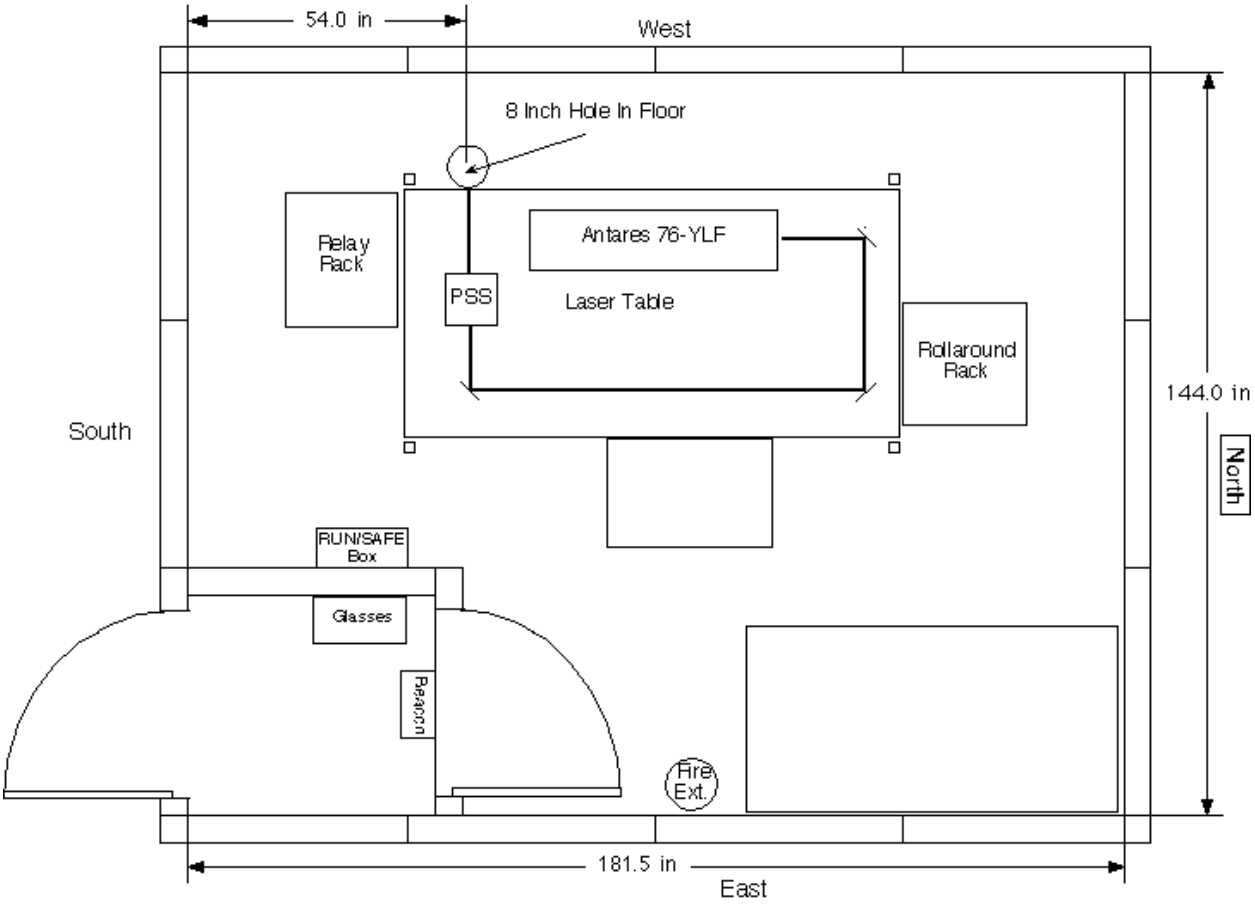
Laser@wavelength	Power output	Optical density
Nd:YLF @1053 nm	100 mW	1.71
Nd:YLF @1053 nm	20 W	4.01
Nd:YLF @527 nm	6 W	3.78

Glendale optics produces a plastic which provides optical densities greater than those in the table above at each wavelength used. We will therefore generally use this material for the goggles. We will also have some prescription glasses which have a sandwich of KG-3 glass and OG550 glass. These have the required densities for the Nd:YLF laser. Staff will be reminded that the plastic goggles offer protection for short periods of time under full power exposure but that they may melt after some exposure.

The MPE for skin exposure in the visible is 200 mW/cm^2. The power density in the laser beam of the Nd:YLF laser is approximately 200 W/cm^2 or about 1000 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. Beam enclosures should be used wherever possible and care should be taken to control stray reflections from optics.

Figure 1. a) Layout of Drive laser enclosure. Locations of fire extinguishers and RunSafe boxes are shown.

Figure 1.



Attachment 1

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

Pages 1–6 of the Antares 76 Series Laser Operator's Manual, Nd:YLF Supplement

Pages 4–10 of the Antares 76 Series Laser Operator's Manual, Chapter One.

Attachment 2

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

Pages 7–36, 40–41 of the Antares 76 Series Laser Operator's Manual, Nd:YLF Supplement

Pages 76–81 of the Antares 76 Series Laser Operator's Manual, Chapter Eight.

Attachment 3

DLE laser safety certification checklist

DLE Safety system certification procedure

( ) Make sure all warning signs are in place.

( ) Verify that the laser cannot be turned on without the key.

( ) Check to see that the laser cannot operate with the Run/Safe box on Safe. Make sure that opening the door to the room shuts off the laser unless the door bypass button is pushed.

( ) Make sure the power supply door interlocks turn off the electrical power to the laser head when the supply door is opened.

( ) Make sure the interlock on the laser head cover turns off the power for the laser when the cover is opened.

( ) Verify that removal of remote interlock plug from the laser causes the laser to shut off.

( ) Verify that the laser emission indicators are illuminated on both the control panel and the laser head when the lamp currents are turned on.

( ) Verify using a low level power meter that the laser safety shutter reduces laser emissions to class I levels.

( ) Verify that the laser must be reset manually when any interlock is tripped.

( ) Verify that shutting off the secondary water shuts off the power supply. This is best done by disconnecting the flow interlock.

( ) Make sure that at least one of the power meters used for power monitoring is calibrated. The other power meters can then be checked against the calibrated unit.

( ) Inspect the laser safety eyewear for integrety and proper wavelength range. Protection level must be at least as good as the LSOP requires.