BROOKHAVEN NATIONAL LABORATORY
LASER CONTROLLED AREA
STANDARD OPERATING PROCEDURE (SOP)

This document defines the safety management program for the laser system listed below. All American National Standard Institute (ANSI) Hazard Class 3b and 4 laser systems must be documented, reviewed, and approved through use of this form. Each system must be reviewed annually.

System description:	LEAF laser systems
Location:	Building 555, LEAF Rooms 21,22, and 23

LINE MANAGEMENT RESPONSIBILITIES

The Owner/Operator for this laser is listed below. The Owner/Operator is the Line Manager of the system and must ensure that work with this laser conforms to the guidance outlined in this form.

Owner/Operator:

Name:	Andrew Cook	*Signature:*	*Date:*
	James Wishart	*Signature:*	*Date:*

AUTHORIZATION

Work with all ANSI Class 3b and 4 laser systems must be planned and documented with this form. Laser system operators must understand and conform to the guidelines contained in this document. This form must be completed, reviewed, and approved before laser operations begin. The following signatures are required.

Christopher Weilandics
BNL LSO *Signature* *Date*

Diane Cabelli
Department ES&H Approval *Signature* *Date*

Alexander Harris
Chemistry Dept. Chair *Signature* *Date*

Jack Preses
BNL ALSO & Chemistry Dept. Laser Safety Coordinator *Signature* *Date*

APPLICABLE LASER OPERATIONS
☒ Operation ☒ Maintenance ☒ Service ☐ Specific Operation ☒ Fiber Optics
Fiber Optics carry light to detectors in a few places.

LASER SYSTEM HAZARD ANALYSIS

Hazard analysis requires information about the laser system characteristics and the configuration of the beam distribution system. The analysis includes both laser (light) and non-laser hazards. A Nominal Hazard Zone (NHZ) analysis must be completed to aid in the identification of appropriate controls.

LASER RADIATION HAZARDS

There are two tables in this section: (1) *Laser System Characteristics* and (2) *Laser System Ocular Hazards*. These provide guidance for understanding the hazards present when working with the lasers and wavelengths specified and are intended to raise awareness of when beams are especially hazardous. The first table identifies and classifies the lasers in use in the laboratory and the second table provides a quantitative indication of the hazard levels associated with each laser and wavelength. The following definitions and concepts are important to understanding and applying the information contained in the tables.

1. MPE (Maximum Permissible Exposure) Limits: The maximum level of laser radiation to which a person may be exposed without hazardous effect or adverse biological changes in the eye or skin.

2. Class 2 Lasers: Lasers emitting low-power visible radiation (400–700 nm) that is a potential eye hazard, but for which eye protection is normally afforded by the natural aversion response to bright light, including the blink reflex. When viewed directly, such lasers cannot cause ocular damage in less than 0.25 s. However, intentionally overriding the natural aversion response *can* result in harm to the eye. For CW lasers, the emission limit is 1 mW.

3. Class 3b Lasers: Direct viewing of Class 3b lasers is a hazard to the unaided eye. The viewing of diffuse reflections may be safe for a short period of time at large enough viewing distances. These factors determining exposure must be carefully considered, even for viewing of diffuse reflections. For CW lasers, the maximum emission limit is 0.5 W.

4. Class 4 Lasers: Viewing direct beams or diffuse reflections from Class 4 lasers is *inherently unsafe*. In addition, lasers in this class can also present a skin hazard, and may pose a fire and fume hazard when interacting with target material.

5. Diffuse Viewing Limit: The diffuse viewing limit is a threshold that is specified in units of energy per pulse (for a *single* laser shot) or in power (for a cw laser) that depends on the wavelength and pulse characteristics of the laser. Lasers capable of emission levels above this limit pose a hazard when viewed in diffuse reflection based on the ANSI definitions for diffuse viewing (600 seconds, 20 cm distance, perfect reflectivity, normal to the card).

In summary, it is important to understand that:
- ***Direct, intrabeam exposure* of the unaided eye to radiation from *all* lasers classified as Class 2 and greater is hazardous.**
- ***Diffuse reflections* from Class 3b beams *may be* hazardous.**
- ***Diffuse reflections* from Class 4 beams *are* hazardous.**

LASER SYSTEM CHARACTERISTICS

Laser Type *(Argon, CO2, etc)*	Wavelength (nm)	ANSI Class	Maximum Power or Energy/Pulse	Pulse Length	Repetition Rate
1. Spectra Physics Millennia Vi diode-pumped Nd:YVO4	532 nm	4	5.5 W	CW	CW
2. Spectra Physics Tsunami Ti:Sapphire Oscillator	798 nm	4	800 mW	100 fs	81.6 MHz
3. Quanta-Ray GCR 170-10 Nd:YAG (seeded)	1064 nm‡ 532 nm 266 nm	4 4 4	850 mJ 450 mJ 90 mJ	8-12 ns 6-11 ns 4-9 ns	10 Hz 10 Hz 10 Hz
4. Quanta-Ray Pro-290-30 Nd:YAG (fixed at 10Hz)	1064 nm‡ 532 nm	4 4	1600 mJ 800 mJ	8-12 ns 6-11 ns	10 Hz 10 Hz
5. Positive Light TSA-10 Ti:Sapphire Amplifier	800 nm 800 nm		6 mJ 10 mJ	1-3 ps 200 ps	10 Hz 10 Hz
6. Homebuilt pulse compressor	800 nm 800 nm		3 mJ 1 mJ	100 fs 100 fs	10 Hz 10 Hz
7. Homebuilt tripler	400 nm 266 nm		1.5 mJ 0.5 mJ	100 fs 100 fs	10 Hz 10 Hz
8. Quantronix Topas 4/800 Optical Parametric Amplifier	200-400 nm 400-700 nm 700-1050 nm 1.05-1.20 um 1.2-1.4 um 1.4-2.6 um		35 uJ 190 uJ 100 uJ 150 uJ 300 uJ 300 uJ	100 fs	10 Hz
9. Power Technology Inc. PMT70(658-80B)G2	658 658	3b	70.9 mW 7.09 uJ	CW 100 uS	CW 60 Hz
10. Power Technology Inc. PMT120(808-150B)G2	808 808	3b	120.1 mW 12.01 uJ	CW 100 uS	CW 60 Hz
11. Power Technology Inc. PMT(LD1415)G2	639 639	3b	35 mW 3.5 uJ	CW 100 uS	CW 60 Hz
12. Power Technology Inc. PMT(LD1438)G2	685 685	3b	60 mW 6 uJ	CW 100 uS	CW 60 Hz
13. Power Technology Inc. PMT90(980-100B)G2	980 980	3b	100 mW 10 uJ	CW 100 uS	CW 60 Hz
14. Power Technology Inc. PMT32(1300-50B)G2	1300 1300	3b	50 mW 5 uJ	CW 100 uS	CW 60 Hz
15. Power Technology Inc. PMT27(1550-40B)G2	1550 1550	3b	40 mW 4 uJ	CW 100 uS	CW 60 Hz
16. Various HeNe and diode alignment lasers	632-690 nm	2, 3a	1-5 mW	CW	CW

17. Daylight Solutions Quantum Cascade Laser Model 21052-MHF	5102-5294 nm	3R	< 0.1 W	CW	1.26×10^8 $\mu W/cm^2$
18. Daylight Solutions Quantum Cascade Laser Model 21049-MHF	4798-5010 nm	3R	< 0.1W	CW	1.26×10^8 $\mu W/cm^2$

‡ 1064 nm outputs are normally terminated inside the laser cabinets, or at the exit in an external beam dump.

Laser System Ocular Hazard Limits

Laser Type *(Argon, CO2, etc)*	Wavelength (nm)	Intrabeam MPE Limit (mJ/cm^2)	Diffuse MPE Limit (mJ/cm^2)	Diffuse Viewing Limit (uJ/pulse)
1. Spectra Physics Millennia Vi diode-pumped Nd:YVO4	532 nm	0.64	10	21 **mW**
2. Spectra Physics Tsunami Ti:Sapphire Oscillator	798 nm	1.92×10^{-8}	7.00×10^{-9}	8.8 **nJ**
3. Quanta-Ray GCR 170-10 Nd:YAG	1064 nm‡ 532 nm 266 nm	1.58×10^{-3} 3.98×10^{-4} 3.00×10^{-2}	5.68×10^{-4} 5.68×10^{-5} 5.00×10^{-4}	714 71.4 628
4. Quanta-Ray Pro-290-30 Nd:YAG	1064 nm‡ 532 nm	1.58×10^{-3} 3.98×10^{-4}	5.68×10^{-4} 5.68×10^{-5}	714 71.4
5. Positive Light TSA-10 Ti:Sapphire Amplifier	800 nm 800 nm	7.52×10^{-6} 7.20×10^{-5}	2.70×10^{-6} 2.59×10^{-5}	3.4 32
6. Homebuilt pulse compressor	800 nm 800nm	7.52×10^{-6} 7.52×10^{-6}	2.70×10^{-6} 2.70×10^{-6}	3.4 3.4
7. Homebuilt tripler	400 nm 266 nm	1.19×10^{-5} 3.00×10^{-2}	1.70×10^{-6} 5.00×10^{-4}	2.1 628
8. Quantronix Topas 4/800 Optical Parametric Amplifier†	200-400 nm 400-700 nm 700-1050 nm 1.05-1.20 um 1.2-1.4 um 1.4-2.6 um	3.00×10^{-2} 1.19×10^{-5} 4.77×10^{-6} 4.74×10^{-5} 3.97×10^{-4} 1.00	5.00×10^{-4} 1.70×10^{-6} 1.71×10^{-6} 1.70×10^{-5} 1.36×10^{-4} 4.62×10^{-1}	628 2.1 2.1 21 171 580 **mJ**
9. Power Technology Inc. PMT70(658-80B)G2	658 658	0.64 9.15×10^{-4}	0.64 1.31×10^{-4}	 164
10. Power Technology Inc. PMT120(808-150B)G2	808 808	1.66 5.98×10^{-4}	1.64 2.15×10^{-4}	 270
11. Power Technology Inc. PMT(LD1415)G2	639 639	2.55 9.15E-04	1.00 1.31E-04	 164.21
12. Power Technology Inc. PMT(LD1438)G2	685 685	2.55 9.15E-04	1.00 1.31E-04	 164.21
13. Power Technology Inc. PMT90(980-100B)G2	980 980	3.68 1.32E-03	3.63 4.74E-04	 596.22
14. Power Technology Inc. PMT32(1300-50B)G2	1300 1300	40.5 1.45E-02	40.0 5.23E-03	 6568.51
15. Power Technology Inc. PMT27(1550-40B)G2	1550 1550	100 1.67	100 1.67	 2.1 J
17. Daylight Solutions Quantum Cascade Laser Model 21052-MHF	5102-5294 nm	0.1 W/cm^2	0.1 W/cm^2	1.26 × 108 μW

18. Daylight Solutions Quantum Cascade Laser Model 21049-MHF	4798-5010 nm	0.10.1 W/cm^2	0.1 W/cm^2	

† MPEs depend greatly on wavelength; MPE listed is the minimum for each range shown.
‡ 1064 nm outputs are normally terminated inside the laser cabinets, or at the exit in an external beam dump.

Please note: The MPEs listed above are per pulse, and are the lowest values from calculations for multiple pulses. For CW lasers, MPEs represent the total allowable exposure. For both pulsed and CW, the time periods for direct viewing/specular reflections are 0.25 seconds for 400-700 nm, and 10 sec outside this range; for diffuse reflections, the time period is 600 seconds. Where multiple pulse corrections have been made for variable repetition rate sources, they were based on the highest possible rate.

Diffuse viewing limits provide a measure of the maximum permissible energy/power for the viewing of specific beams on cards based on the ANSI definitions for diffuse viewing (600 seconds, 20 cm distance, perfect reflectivity, normal to the card). These calculations involve many factors, and it may not be safe to simply scale these factors for different conditions.

☒ **Cryogen Use**

Describe type, quantity, and use.

Liquid nitrogen is used occasionally for the cooling of a CCD camera and samples.

☒ **Chemicals & Compressed Gasses**

Describe type, quantity, and use.

Compressed Nitrogen (~100psi max) from a generator in the chase is used as purge for laser cavities.
Small amounts (< 1 liter) of methanol and acetone used for cleaning optics.
Small quantities of samples (< 10 ml in cells, < 1000 ml in flow systems) may be present containing various solvents and solutes. The preparation and handling of samples is covered in ESR CO-4-9.

☒ **Electrical Hazards**

Description *(Describe the power supply to the system).*

All lasers in this facility have commercial enclosed power supplies, and under normal operating conditions present no hazard. High currents and voltages are present inside power supplies, and may remain hazardous even after the power is shut off due to the large capacitors present. Interiors of laser heads such as those of Nd:YAG lasers in the facility also present high voltage and current risks. Where deemed necessary by the manufacturers, particularly hazardous areas have warning labels. In no case is routine operation allowed with either power supply or laser head cabinets open. In some cases, such as optical alignment in laser heads as well as other maintenance tasks, it is necessary to operate lasers with cabinet interlocks defeated. In such cases, special attention must be given to the possibility of both electrical and optical hazards. In some cases, specific procedures exist and must be followed as described in the manufacturer's manuals. We have minimized risks further by installing several plastic covers in the Nd:YAG laser head to isolate high voltage and current risk areas from the user. This includes the flashlamp terminals as well as the Pockels' cell. These shall not be removed during alignment procedures.

The TSA-10 amplifier has high voltage drivers inside the non-interlocked case to power the 2 Pockels' cells in the regenerative amplifier section. The connections are covered by metal caps labeled with high voltage stickers. In no instance can these devices be energized without the protective caps in place. The 500 VDC power for the drivers is current limited (10mA). Care must be taken with the power cables to avoid cutting them or exposing the hot pins when it is required to disconnect them.

☒ **Other Special Equipment**

Description *(Equipment used with the laser[s]).*

Leaf accelerator and detection systems: described in the LEAF SAD, which was approved 1/97.
Hammamatsu Streak camera used for time resolved emission work. Photodiodes, photomultiplier tubes, and other light sources such as 75 Watt Xenon short-arc lamps (typically ozone free, but when needed possibly not – in which case venting of produced ozone will be done when necessary) are used in conjunction with lasers and depending on sample needs and experimental detection system. Note that many of these devices must be handled with care and in accordance with the manufacturer instructions as high voltages and/or currents and intense light sources are involved.

Laser System Configuration:

Describe the system controls *(keys, switch panels, computer controls),* beam path, and optics *(provide a functional/block diagram for complicated beam paths)*.

All primary lasers are located in the laser room of the LEAF facility. Beams used for generating electrons in the LEAF gun and for diagnostic probes are transported through tubes in the wall to the LEAF vault area. In the vault area, a laser probe beam (max 1 mJ, various colors) crosses from one table to another using a gravity shutter and tube (shutter is closed if safety tube removed). In another experiment, an excitation beam (max 6 mJ, various colors) travels from the small table in front of the laser room exit tube to the table at electron beam port B near the vault entrance. In this case, the beam passes across floor space near the electron beam pipe. When this beam is present, the area will be roped off with a plastic safety chain and a sign noting the hazard. Otherwise, all laser beams (thus the nominal hazard zone or NHZ) are confined to the tabletops under normal operating conditions.

All primary pump lasers (Nd:YAG and diode pumped Nd:YVO4) are enabled by key switches and power breakers on the power supplies, and are mostly activated by remote control units.

All primary class 4 pump laser beams are enclosed in beam tubes between laser enclosures in areas where it is possible to easily and inadvertently obstruct the beam. For normal operation these tubes must be kept in place due to the very high energy/pulse in these beams.

In general, no laser light is allowed to exit the LCA (laser room and vault). An exception is the small amount of light from the Ti:Sapphire oscillator is coupled into a fiber in the laser room. This fiber terminates in the control room outside the LCA into a detector used for experiment timing and triggering. Under no circumstances is this fiber (labeled with a warning) to be disconnected from the detector during operation.

Another exception is beams from the class 3b laser diode modules and 3R quantum cascade lasers when they are used as probe light for experiments. At such times, the modules are operated in the vault area, not the laser room. Laser diode modules are driven from a key switched control unit and external TTL trigger source. The external source will either allow CW operation, or more typically pulsed at either 60 Hz or single pulse. Since they are not interlocked, when these modules are in use a warning sign will be posted to notify those entering the area.Light is routed from these modules through samples, and then out of the vault through the hole in the wall normally used for arc-lamp probe light. In the control room, the laser light must be contained by barriers and properly terminated in such a way that inadvertent exposure to direct or scattered laser light is prevented. When not in use, they must be shuttered or switched off. The control room will be posted outside the entrance and in the vault door. Bystanders will not be permitted in the control room or vault during alignment.

DEVELOP CONTROLS
IDENTIFY ES&H STANDARDS

Recognition, evaluation, and control of laser hazards are governed by the following documents.

American National Standards Institute (ANSI) Standard for Safe Use of Lasers;
(ANSI Z136.1-2000)

BNL SBMS Laser Safety Subject Area

Brookhaven National Laboratory Environment Safety and Health Standard: 1.5.3 INTERLOCK SAFETY FOR PROTECTION OF PERSONNEL

ENGINEERING CONTROLS

☒ Beam Enclosures
☒ Beam Stop or Attenuator
☒ Activation Warning System
☐ Ventilation
☒ Protective Housing Interlocks
☒ Key Controls
☒ Other Interlocks
☒ Emission Delay
☐ Other

Describe each of the controls in the space provided below this text. Interlocks and alarm systems must have a design review and must be operationally tested every six months. Controls incorporated by the laser manufacturer may be referenced in the manuals for these devices. **If any of the controls utilized in this installation requires a design review, a copy of the design review documentation and written testing protocol must be on file. Completed interlock testing checklists should be retained to document the testing history.**

Engineering Controls Description:

All commercial lasers are outfitted by the manufacturer with the federally mandated labels, beam stops, audible or visual activation indicators, key controls, protective housing interlocks, remote interlock connectors, and emission delays.

Beam enclosures: During standard operation, lasers are only operated with the covers in place, with laser output only at the labeled apertures. Class 4 pump laser beams are enclosed in rigid tubes where they are accessible. Class 4 beams do not cross any floor space where someone could walk into the beam.

Interlock system: The LEAF facility has two Laser Controlled Areas (LCAs): the laser room itself, and the vault area where the accelerator is. All class 4 pump lasers and the 3b sources they pump are located in the laser room, and are connected to a door interlock system. Emergency or unauthorized entry to this area will shut down all of the class 4 and 3b lasers in the facility by shutting down the pump laser power supplies. Controlled access is implemented with a pushbutton at the doors, which allows ~20 seconds for authorized users to enter or leave the laser controlled area without shutting down the lasers. If someone enters or leaves the LCA without using the bypass, or a door is held open longer than ~20 seconds, all lasers immediately cease output. Laser beams are brought through tubes in the concrete wall separating the laser room from the vault. Before entering these tubes however, they are intercepted by mechanical

shutters that form the basis for the interlock system for the vault LCA. Similar to the laser room, the vault area is protected by entry interlocks, but which only serve to close the shutters instead of turning off the laser power supplies if tripped. The vault area uses electric-eye entry interlocks rather than door interlocks to satisfy radiation protection rules that state that no personnel can be in the vault area with the doors closed (and radiation interlocks potentially active).

The interlock system is tested every six months, and is part of the LEAF area total interlock system. This contains interlocks for not just the lasers, but also the accelerator radiation safety system. The interlock design has been qualified during an accelerator readiness review (ARR) as a “catastrophic” level system. It also follows the Chemistry department standard for laser control areas, and includes a flashing “laser on” sign for the laser room, and yellow lamp indicators for when the laser interlock in the vault area LCA is enabled. Documentation and inspection records are maintained in the file cabinet at LEAF, along with certification, design, and test procedures.

ADMINISTRATIVE CONTROLS

☒ Laser Controlled Area ☒ Signs ☒ Labels ☒ Operating Limits

The format and wording of laser signs and labels are mandated by BNL and ANSI standards. Only the standard signs are acceptable. Standard signs are available from the BNL Laser Safety Officer.

All lasers must have a standard label indicating the system's wavelength, power, and ANSI hazard class. Required labels must remain legible and attached. The manufacturer should label commercial systems.

Standard Operating Procedures (SOPs) are required for laser system operation, maintenance (including alignment), and servicing. The SOPs need only contain the information necessary to perform these tasks and identify appropriate control measures including postings and personal protective equipment. The BNL Laser Safety Officer must approve SOPs and copies should be available at the laser installation for reference and field verification of stated control measures.

Administrative Controls Description:

General comments for all work in LEAF LCAs:

1. All lasers under this SOP are operated in the LCAs at LEAF described above. Appropriate warning signs are posted at each entrance. All lasers have mandated labels. Flashing warning signs, activated whenever the interlock system is live, are mounted outside the main laser room entrances. Yellow warning lights are lit at the doors to the vault when its interlock system is active.

2. Remember that Class 4 laser beams are dangerous to view even in diffuse reflection. Class 4 limits and MPEs for all wavelengths emitted by lasers covered by this SOP are listed in the section "Analyze the Laser System Hazards" above, and eyewear requirements are listed in the eyewear table below. Requirements for when/what eyewear is required are discussed below.

3. Before working within the laser nominal hazard zones at LEAF, users must remove personal objects that might intercept a beam accidentally during work. This is especially true for shiny BNL badges attached to ropes around your neck or even clipped to shirts, and things like rings and watches when making laser adjustments. Such objects make very good reflectors that could cause specularly reflected beams to leave the NHZ in an uncontrolled fashion, possibly injuring yourself or a co-worker.

4. Users must use good sense in avoiding actions that place themselves or co-workers at risk of laser-related injuries. Users must be aware of others in the LCA, especially those who enter the area while work is in progress.

5. If at any time a user is unsure of the correct procedure to follow, the user shall **STOP** and seek the advice of the responsible laser owner/operator, and/or the LSO/ALSO. No changes to procedures can be made without approval by the owner/operator.

6. Definitions:
    a. Operation – use of laser systems; will involve energy adjustments via waveplate/polarizer pairs already in place.
    b. Gross alignment – any procedure where beams are not already on optical components, or those that may lead to beams leaving established paths and optical surfaces.
    c. Simple/normal alignment – procedures where beams do not leave established beam paths/optical surfaces/beam stops.

Operation SOP:

1. Except during alignment procedures, all primary and specular beams, as well as diffuse reflections from class 3b and 4 beams must be contained on the laser tables using non-combustible diffusely reflecting or absorbing laser beam stops that do not create hazardous vapors. Class 3b and 4 beams between tables across open floor space must be enclosed in protective tubes, except as specifically noted in the "Configuration" section above. All optics must be solidly attached to laser tables so that accidental "bumps" cannot send beams in unknown directions. Physical protection must be provided from vertical beams or any other situation where unexpected exposure might occur. Under these conditions, the nominal hazard zone is confined to the areas above the laser tables, and eye protection as specified below is required for work within the nominal hazard zone. *Any light outside the NHZ must be at levels at or below the maximum permissible exposure (MPE).*

2. Lasers should be operated at the minimum intensity consistent with experimental requirements.

3. Nd:YAG lasers must be used with enclosed termination of all unused harmonics.

4. Users must know and follow the routine operation instructions for all lasers as described in the manuals provided by the laser vendors. Users must also be familiar with the LEAF Laser System Manual and the procedures there for laser system turn on/off.

5. A common operation procedure is the adjustment of the amplifier pump energy, by rotating waveplates in the amplifier box. This does not involve moving any beams, however it does involve opening the amplifier cover thus users must:
    a. Wear eye protection for 800 nm.
    b. Be aware of the intense 532 nm pump beam because of the large skin burn hazard. Because of this hazard, eye protection for 532 nm is not required so that users can see the beam and know where not to put fingers or other items. However, this then requires exceptionally high attention and care be taken to avoid the possibility of causing a stray or diffuse reflection.
    c. Do not put any objects (fingers, watches, cards) in any beams.
    d. Only open the amplifier cover as much as necessary, and close the covers when done.

6. Another common procedure is measuring the output energy of the amplifier and it's third harmonic:
    a. Wear eye protection for invisible beams including both 800 nm and 266 nm.
    b. Do not put any objects (fingers, watches, cards) in any beams.

7. Special care must be exercised when using the OPA, due to the possibility of multiple wavelengths being present at the same time. Users of the OPA must be aware of which wavelengths may be present during use, and protect themselves and co-workers accordingly. While it is possible to determine the combination of possible colors by understanding the OPA operation, it can also be can be determined by using the tuning information normally stored next to the OPA for easy reference. In addition, the wavelength of the OPA output will be posted on the white board outside the LCA next to the box containing the laser safety eyewear as well as near the vault door if the OPA is being used in that area so that the correct eyewear can be worn by the next person to enter the LCA.

Alignment SOP:

1. There shall be no intentional intrabeam viewing with the eye!!

2. Maintain good housekeeping practices on laser tables; keep the area where you will be working clear of excess objects that might scatter a beam unpredictably, and keep combustible materials away from class 4 hazards.

3. Consider the use of low power class 1-3a coaxial CW alignment lasers when convenient.

4. During alignment procedures, only persons immediately involved in the procedure are to be in the LCA. These individuals must have appropriate training and be listed in this document as authorized laser users.

5. When it is possible that hazardous beams are not completely contained on the laser tables, the room must be posted with a temporary alignment warning sign on the door warning those that may enter not to until the procedures are completed and the sign removed.

6. During all times when the possibility for inadvertent exposure to laser light exists, appropriate laser safety eyewear must be worn. The appropriate ratings are listed in the PPE section, and discussed further below.

7. Definite termination of the beam path must be in place before the beam is allowed to propagate. Use moveable beam stops to ensure that uncontrolled propagation does not occur.

8. Alignment procedures are always to be performed with the minimum practical laser power levels and repetition rates. This is especially true for the output of the primary pump lasers. In the case of the Quanta-Ray Nd:YAG lasers this can be achieved by the use of long pulse mode that dramatically reduces the high-energy 532 nm output, and produces a much longer pulse width. Since you must be able to see this beam in order to align it, refer to the comments in #14 below. The beam energy can be further reduced if necessary by tweaking the harmonic generator off the maximum, though this is typically not useful since this will also move the beam some. Inside the TSA amplifier, use the waveplates to minimize the 532 nm energy to the point (nearly minimum) where a good quality beam is just visible before doing alignments.

9. Following a new laser beam set-up or change in alignment, a survey of the beam path will be conducted to verify that all unwanted beams and reflections have been properly terminated. Opaque barriers will be used to confine low intensity stray reflections and scattered light to the optical tables. Any unwanted primary or specular beams in excess of class 4 thresholds will be terminated in a beam stop within the NHZ that does not produce hazardous diffuse reflections.

10. Gross alignment of beams from class 4 lasers into experiments or tunable lasers should be done with beams attenuated as far below class 4 thresholds as possible, with eye protection adequate for the beam in use.

11. Routine laser-specific alignment procedures may be simple or complex. Where they exist, specific procedures outlined in the operation and alignment manuals supplied by the manufacturers must be followed.

12. Pre-position optical components during gross alignment as best as possible and bolt them down before allowing beams to propagate.

13. Be aware of the potential for errant reflections (stray beams) from and leaked beams transmitted through components such as polarizers and dielectric mirrors. For example, do not use or rotate calcite polarizers with escape windows without first being sure that all exit beams will be blocked. Check for stray beams at each step and again after completing all alignment steps.

14. In some circumstances, it may not be possible to perform certain alignment tasks while wearing blocking eyewear. Unobstructed viewing of diffuse reflections is a last recourse, after exhausting

other possibilities like power meters, viewers and emissive cards. In cases where it is necessary to view diffuse reflections of visible beams in order to perform an alignment, the following apply:

a. If you are not absolutely sure about the safety of the procedure you are doing, stop and seek assistance from the appropriate PI and/or other reference person such as the department LSC or BNL LSO/ALSO.
b. Heightened awareness of beam hazards is necessary during such procedures. Special care and planning is needed to insure that unexpected specular reflections do not occur, and that hazards from other beam sources are controlled.
c. Be sure that diffuse viewing is non-hazardous. Consult the MPE table above and the eyewear PPE table below for information about diffuse reflections of the primary laser sources. See also the discussion in the eyewear section on some specific procedures, as well as general methods to limit the hazard to below the MPE by using primarily lower power, distance from the source, and viewing time.
d. Use the minimum possible energy consistent with the task at hand.
e. Discuss new procedures with a colleague in order to identify safe methods.
f. Use only cards without shiny surfaces to produce only diffuse reflections, and angle cards away from the face to avoid any possibility of specular reflections.
g. Minimize viewing time of the beam on a card; often only a second or two is necessary to align a beam.
h. Replace eyewear immediately upon completing task. Often it is enough to simply momentarily raise glasses without removing them at all.
i. Do not put your face close to the source of diffuse reflections; use cards at arm's length away when possible.

Maintenance SOP:

1. Certain approved laser users will conduct occasional routine maintenance. This includes procedures such as replacement of the flash lamps and cooling water in the Nd:YAG lasers, optics cleaning and/or replacements in all lasers. All of these procedures are to be conducted in strict accordance with the methods described in the laser manuals provided by the manufacturers if they exist, and only by individuals with appropriate training who are listed in this document. Any maintenance on BNL constructed equipment will only be performed under the direction of the appropriate PI.

2. Non-routine maintenance and troubleshooting is a serious matter, as injury or damage to equipment could result from actions taken in unfamiliar circumstances. When an uncharacterized fault condition exists, some actions that would be safe under ordinary conditions may have unsuspected hazards. Diagnostic work on optics or electronics will thus only be undertaken strictly following specific instructions in the manufacturer's laser manual, or in consultation with the manufacturer's service engineering staff. When there is any uncertainty about the safety of a diagnostic procedure, don't do it, and seek additional expert guidance. The laser manufacturer's field service engineers may be required to perform specialized maintenance tasks for which lab employees lack specific expertise and training.

3. In certain cases maintenance of laser components requires working with the laser interlock defeated, usually the interlock on the laser head case. Under these conditions there are several additional hazards one must be aware of. As discussed earlier a high voltage area is exposed. To minimize the risk of accidental touching, plastic covers are used to mask these areas. They will be replaced if they must be removed for the maintenance work, before the laser is operated again. Another issue one must be aware of is the increased amount of IR light present and also the possibility of an increased amount of second harmonic light (532 nm) in the Nd:YAG head. This requires one to double check the protective eyewear being worn to minimize the possibility of stray light entering eye. The last issue is when the cooling water is replaced. In this case, the

laser power supply cabinet cover is removed. To minimize risk of energizing the power supply the water pump will be run with the interlock enabled, which gives ~60 seconds before the power supply shuts down and does not allow the lamps to flash. In addition, users will position themselves and the power supply to maintain a safe distance from potentially energized components.

4. Procedures that the laser manufacturer's field service engineers perform may contain additional work under defeated interlocks. In these cases, Brookhaven personal overseeing the engineer will maintain a safe distance from any open electrical hazards and wear all relevant PPE.

CONFIGURATION CONTROL

A checklist must be developed for the purpose of verifying the placement and/or status of components that are used to mitigate hazards by configuration control. Examples include any protective housings, beam stops, beam enclosures, and any critical optics *(mirrors or lenses that could misdirect the beam and result in personnel hazard)*. Entries should also be included to ensure placement of required signs and labels and status of interlock verification. Completed checklists must be posted at the laser location. The checklist does not have to be redone unless there has been a system modification, extended shutdown, or change of operations.

In general, engineering controls of the type describe above are not changed during normal operation. During routine operation and simple alignment procedures, certain laser covers may be opened or removed for short periods of time to allow for simple adjustments. After such operations, the covers are replaced and do not require rechecking of the full configuration control list below. In other cases however, such as during gross alignment procedures, more comprehensive work is done. In such cases, the room must be posted with an alignment warning sign, which is not removed until the normal operating condition is restored with all controls back in place. This includes a sweep of the area to ensure that no beams or intense diffuse reflections leave the optical tables. The following checklist of items are finally required to be in place at completion of gross alignment before resuming normal operation:

1. Laser enclosure covers:
    a. All Nd:YAGs
    b. Ti:Sapphire oscillator
    c. Ti:Sapphire amplifier
    d. Pulse compressor
    e. Third harmonic generator
    f. OPA
2. Beam tubes:
    a. From Nd:YAG pump to amplifier box (large energy)
    b. From third harmonic generator to energy control section (inadvertent exposure)
3. Beam dump for 1064nm light from Lab170 Nd:YAG when it is in operation
4. Shutters:
    a. UV shutter providing vault interlock
    b. Probe shutter providing vault interlock

Since this laser system is used for a wide variety of research topics, changes in beamstops, optical components and subsequent optical paths are common. Such changes must be consistent with the safety envelope defined by this document. When changes occur, the following procedures must be followed:

1. Communication with other users and the owner/operator is crucial. This can be accomplished by posting a sign on the door to the LCA to note changes, or using the white board by the laser room door. In some cases where procedural changes are required, contacting all of the people who use the LCA may be necessary.
2. After making any changes, the area must be checked to be sure that no new hazardous condition is created. This involves items described in the alignment section of the SOP above, key among which are that beams are all in well defined paths, and confined to the optical tables.

PERSONAL PROTECTIVE EQUIPMENT

☐ Skin Protection ☒ Eye Wear

Skin Protection: For UV lasers or lasers that may generate incidental UV in excess of maximum permissible exposure (MPE) describe the nature of the hazard and the steps that will be taken to protect against the hazard.

The 266 nm Nd:YAG harmonic of some lasers in this facility may have intensities in excess of skin MPE. UV beams propagated across otherwise accessible floor space will be enclosed to prevent skin exposure. Operators will minimize risk of skin exposure by:

1. Using reduced power during alignment procedures where possible.
2. If not possible to avoid exposure or reduce the power far enough, then wear long sleeves and other skin protection during alignment procedures.
3. Enclose class 4 beams in rigid tubes where personnel are likely to intercept them.

Eye Wear: All laser protective eyewear must be clearly labeled with the optical density and wavelength for which protection is afforded. Eyewear should be stored in a designated sanitary location. Color - coding or other distinctive identification of laser protective eyewear is recommended in multi-laser environments. Eyewear must be routinely checked for cleanliness and lens surface damage.

1. For invisible beams, eye protection against the full beam must be worn at all times unless the beam is fully enclosed.
2. For visible beams, eye protection against the full beam must be worn at all times during gross beam alignment.
3. Where hazardous diffuse reflections are possible, eye protection with an adequate Optical Density for diffuse reflections must be worn within the nominal hazard zone at all times.
4. If you need to operate the laser without wearing eye protection against all wavelengths present, explain the precautions that will be taken to prevent eye injury:

a. During normal operation, protection from invisible beams is always required, but it is not necessary to wear eyewear protection against all visible wavelengths provided all beams are controlled as described in the operation and alignment SOPs above. The key features of this requirement are that all beams are enclosed in the NHZ, and no adjustments to visible beams are being made.
b. Alignment of the amplifier 532 nm pump beam will require removal of visible eye protection. This is discussed along with precautions in the alignment SOP above. A key feature of this procedure is running the Nd:YAG in long pulse mode to drop the peak power and total energy/pulse (actual energy varies). Be aware however that while far safer, this beam is still hazardous, and has an energy high enough to cause eye damage for specular reflections. In normal circumstances, this beam is easily viewable on the optics without the need for diffusely reflecting cards. Special care and thought must be taken if the beam must be grossly steered to insure it does not cause hazardous reflections. Diffuse beam viewing may be needed and is permissible with cards as long as it is only momentary (< 6 seconds) and at the greatest possible distance (> 40 cm).
c. Alignment of visible 3b diode modules in the vault may require unprotected diffuse viewing, as IR viewers and upconversion viewing cards do not work sufficiently. When this must be done, precautions in the alignment SOP must be followed. This will only be done while the

diodes are pulsed (not CW) as noted in the laser characteristics above. In this circumstance while only marginally hazardous, the required intrabeam ODs are 1.0-1.3 and thus require heightened awareness and care. Diffuse reflections from cards typically used for alignment are safe provided reasonable care is taken.

d. For alignment of the quantum cascade lasers, safety glasses with an OD of 2.1 (intrabeam) are appropriate for 100mW beams, and no glasses are required for diffuse reflections. Polycarbonate glasses will be used when the IR beam is exposed for alignment in the control room (when the shields are not in place). If the actually measured IR power is more like 10mW, required ODs drop to 1.1, and glasses will not be worn.

e. Internal alignment of the OPA may require unprotected viewing. As noted in the Operation SOP, this device generates many concurrent different wavelengths, and as such requires heightened care during alignment. At a bare minimum, protection for the pump beam at 800 nm is mandatory, and special precautions such as those listed in the Alignment SOP are required. Awareness of which wavelengths are present where and when in the OPA is needed; this is detailed in the manual. Typically the pump for last stage of amplification is blocked with a card, and OPG and white light spots are viewed using a diffusely reflecting card after the first and second stages of amplification. In these cases diffuse viewing does not require eye protection. Final alignment is done by viewing a variety of differently colored spots on a card external to the OPA in order to overlap them. During this procedure, viewing must be done for as short periods as possible (< 6 seconds) and at distances as long as possible (> 40 cm) to reduce the hazard below the MPE.

f. Alignment of visible output from the OPA may require unprotected viewing in both the laser room and vault. Again, precautions detailed ion the Alignment SOP above must be followed. In particular extra caution and planning is needed to avoid the possibility of specular exposure including definite termination of the beam and coworker awareness must be observed. As before, most alignment will be accomplished using diffusely reflecting cards. To avoid hazardous exposure, viewing must be momentary (< 6 seconds), and at arm's length (> 40 cm).

Define eyewear optical density requirements by calculation or manufacturer reference and list other factors considered for eyewear selection. The BNL Laser Safety Officer will assist with any required calculations.

EYE WEAR SPECIFICATIONS

Laser System Hazard	Wavelength (nm)	Calculated Intra-beam Optical Density	Diffuse Optical Density *	NHZ ** (meters)	Appropriate Eye Wear ***
1. Spectra Physics Millennia Vi diode-pumped Nd:YVO4	532 nm	3.75	2.41	3.24	L228
2. Spectra Physics Tsunami Ti:Sapphire Oscillator	798 nm	3.12	N/A	N/A	L568
3. Quanta-Ray GCR 170-10 Nd:YAG	1064 nm‡	6.15	3.08	6.9	L568, L228
	532 nm	6.47	3.80	15.9	L228
	266 nm	5.58	2.16	2.4	L568, L228, GBM-64-N
4. Quanta-Ray Pro-290-30 Nd:YAG	1064 nm‡	6.42	3.35	9.5	L568, L228
	532 nm	6.72	4.05	21.2	L228
5. Positive Light TSA-10 Ti:Sapphire Amplifier	800 nm	6.32	3.25	8.4	L568
	800 nm	5.56	2.49	3.5	L568
6. Homebuilt pulse compressor	800 nm	6.02	2.95	6.0	L568
	800 nm	5.54	2.47	3.4	L568, GBM-64-N
7. Homebuilt tripler	400 nm	5.51	2.85	5.3	L228
	266 nm	3.33	N/A	N/A	L568, GBM-64-N
8. Quantronix Topas 4/800 Optical Parametric Amplifier†	200-400 nm	2.17	N/A	N/A	L568
	400-700 nm	4.62	1.95	1.9	
	700-1050 nm	4.74	1.67	1.4	L568
	1.05-1.20 um	3.91	0.85	0.5	L568
	1.2-1.4 um	3.31	0.24	0.3	L568
	1.4-2.6 um	1.90	N/A	N/A	
9. Power Technology Inc. PMT70(658-80B)G2	658	1.86	0.53	0.05	L568
	658	1.30	N/A	N/A	L568
10. Power Technology Inc. PMT120(808-150B)G2	808	2.27	N/A	N/A	L568, GBM-64-N
	808	1.72	N/A	N/A	L568, GBM-64-N

11. Power Technology Inc. PMT(LD1415)G2	639 639	1.55 1.0	N/A N/A	N/A N/A	L568 L568
12. Power Technology Inc. PMT(LD1438)G2	685 685	1.79 1.23	N/A N/A	N/A N/A	L568 L568
13. Power Technology Inc. PMT90(980-100B)G2	980 980	1.85 1.29	N/A N/A	N/A N/A	L568, GBM-64-N L568, GBM-64-N
14. Power Technology Inc. PMT32(1300-50B)G2	1300 1300	0.51 N/A	N/A N/A	N/A N/A	L568 N/A
15. Power Technology Inc. PMT27(1550-40B)G2	1550 1550	1.71 N/A	N/A N/A	N/A N/A	L568 N/A
17. Daylight Solutions Quantum Cascade Laser Model 21052-MHF	5102-5294 nm	1.80	N/A	N/A	Measured and certified polycarbonate (MSA Z87+)
18. Daylight Solutions Quantum Cascade Laser Model 21049-MHF	4798-5010 nm	1.80	N/A	N/A	Measured and certified polycarbonate (MSA Z87+)

* Diffuse ODs are calculated assuming a 600 second exposure, a viewing distance of 20 cm, perfect reflectivity, and viewed normal to the surface. The ODs required can decrease for more typical conditions in the laboratory:

a. Every time the viewing distance doubles, the OD goes down by 0.6
b. Generally, the OD drops by ~1.0 for each factor of 10 shorter in the viewing time
c. For a 45 degree to the normal viewing angle, the OD drops by 0.15
d. For reflectivities lower than 1, the OD will drop by $\log_{10}$[reflectivity]
e. As the energy/power drops, the OD will drop by $\log_{10}$[I/I0]

Thus for example, the alignment of the 800 nm probe beam, derived from source #8 can be done without safety glasses if: a) viewing distance is at arm's length to diffusive card (my arm ~ 80cm) drops OD by 1.2; b) viewing time is ~2 sec drops OD by 2.5; e) energy after beams splitters ~1 mJ (a third) drops OD by 0.5 for a net OD drop of 4.3 making glasses unnecessary for diffuse viewing only. Note that the intrabeam hazard is unchanged.

**The Nominal Hazard Zone is that zone or distance inside which exists a hazard to the eye from a diffuse reflection (as well as direct or specularly reflected light) for the time specified, in this case, 600 seconds (10 minutes).

***Specified eyewear may not be the only possible option, but represents an approved choice; depending on other laser hazards present in the lab, other eyewear may be acceptable or even preferable provided the optical densities are equivalent or greater than those required. Note that some of these beams in the vault area are not as intense as in the laser room, thus appropriately lower ODs are acceptable. Under normal operation since visible beams such as 400 and 532 are controlled, the best choice for glasses are the Uvex L568, as they block all of the invisible beams but leave a fairly good visual throughput.

† ODs depend greatly on wavelength; OD listed is the minimum for each range shown. Due to the broad range of output colors of the OPA, users must use good sense in selecting appropriate eyewear during alignment. In some cases it will not be possible to have eyewear to protect from all available wavelengths, in which case the user must use extreme care, and follow the rules in #14 of the alignment SOP above.

‡ 1064 nm outputs are normally terminated inside the laser cabinets, or at the exit in an external beam dump, and in this condition require no eye protection.

EYE WEAR SPECIFICATIONS

Laser System Eyewear Identification				Wavelengths (nm)	Optical Density
#	Model	Type	Color		
4	Uvex L568	Spectacle		200-350 † 633 750-1050nm 1050-1064nm 1064-1300nm † 1300-1400nm † 1400-1580nm † 10600nm	5.8+ 1-2 7+ 8+ 5+ 4+ 2+ 5+
2	Uvex L228	Spectacle		190-532nm 633nm 750-1050nm 1050-1064nm	8+ 1-2 7+ 8+
1	Uvex L328	Goggle		633nm 190-532nm, 750-1050nm 1050-1064nm	1-2 8+ 7+ 8+
1	Uvex L267	Spectacle		190-532nm 1050-1064nm 10600nm	8+ 8+ 7+
3	GPT Laser Gard Argon NDGA #2175	Goggle		353nm 530 1060nm	20 7 10
1	GPT Laser Gard LGB	Goggle		200-400nm 488 514.5nm 530nm 840 1060nm	14 11 7 4 4 4
2	GPT/Glendale GBM-64-N	Spectacle	Amber	190-532 520-532 710-750 750-850 790-810 ‡ 850-1080 5000-11000	9+ 7+ 3+ 5+ 5.8+ 7+ 7+

EYE WEAR SPECIFICATIONS					
Laser System Eyewear Identification				Wavelengths (nm)	Optical Density
#	Model	Type	Color		
2	GPT/Glendale GBG-64-N	Goggle	Amber	190-532 520-532 710-750 750-850 790-810 ‡ 850-1080 5000-11000	9+ 7+ 3+ 5+ 5.8+ 7+ 7+
3	(MSA Z87+)	Goggle	Clear	> 1000 nm †§	4.3+

For normal conditions, appropriate eyewear for each area is stored in clear compartment boxes mounted on the walls at the entry to both the LEAF laser room and vault.

† Glasses not marked for these wavelengths. Data from testing in our lab; results are stored in LCA notebook.

‡ Glasses not marked for these wavelengths. Data provided by Kentek Corporation; results are stored in LCA notebook.

§ When quantum cascade laser are used, the beam path will be delineated with a yellow chain to prevent persons from walking through the beam.

TRAINING

LASER SAFETY TRAINING

Laser Operators must complete sufficient training to assure that they can identify and control the risks presented by the laser systems they use. Owners/Operators and Qualified Laser Operators must complete the awareness level BNL World Wide Web based training course (TQ-LASER) every two years.

Qualified Laser Operators must also complete system-specific orientation with the system owner/operator. **System-specific training must be documented with a checklist that includes**

- Trainee name and signature
- Owner/Operator signature
- Date
- Brief list of topics covered e.g.
  - Review of SOPs;
  - Review of working procedures, and other program specific documentation.

All laser safety training must be repeated every two years.

SOP SIGNATURES

The signatures of the personnel listed in the following table indicate that these personnel have read and understood the contents of this SOP and agree to adhere to the guidelines detailed in therein. The signature of the Owner/Operator indicates that the Owner/Operator has reviewed this SOP with the User to ensure that its contents have been clearly communicated and understood.

SOP Signatures are necessary but do not document complete authorization. Other required training elements and documentation are described immediately above in the "Laser Safety Training" section. Only persons who have signed below, and completed/have documented the required training may operate the lasers covered by this SOP.

User Printed Name	Signature	Date	Owner/Operator Signature
Owner: Andrew Cook	———		
Owner: James Wishart	———		
John Miller			
Jack Preses			

Training certification for laser users in building 555 rooms 23,25 (LEAF)

Training for Laser User:	
On laser system:	All lasers at LEAF

Topic	Signature of user/date (Initial of laser owner)
Instruction in interlock configuration for laser access restricted area (room or enclosure)	
Description of laser output characteristics (wavelength, pulse energy, length of pulse and/or average power)	
Checklist of major hazards (including laser light, compressed gases, cryogens, electrical): • Wear eye protection for invisible beams at all times when laser emission is possible. This includes both the laser room and the vault. • Never intentionally direct a beam towards your face, or put your face in line with any laser beam: **do not depend on eyewear to protect you**. • Be aware of what your co-workers are doing, and alert them to any potentially hazardous conditions or actions. • Do not enter areas posted with an alignment sign unless you have permission. • Use minimum laser power possible during alignment. • Use plain or fluorescent sensor cards or IR viewers when possible to aid in locating laser beams. • Locate all surface reflections and terminate with appropriate beam dumps. • Use *COMMON SENSE* and *CARE* in performing all alignments. Think about the consequences of your actions, as it pertains to the safety of yourself, others and equipment. • If unsure about what you are doing, STOP! Ask a knowledgeable person what to do before proceeding. • Don't grossly align lasers at high power. • Don't place optical elements into the laser beam without first blocking the beam with an appropriate dump. • Don't wear any reflective materials (such as rings, watches, BNL badge) on your hands or arms, or around your neck during the arraignment. • No *unauthorized* personnel are allowed in the laboratory during laser operation. • When adjusting the amplifier pump energies, take care not to put objects and/or fingers in the pump beam.	
Operation: Power on/off, shutter operation, normal experimental configuration, nominal hazard zone where class IV intra-beam beam protection is required, adjustment of beam energies via waveplate/polarizers.	
Simple Alignment: UV on cathode, minor experimental alignment (delay line, vault experimental table).	
Normal maintenance: Changing laser lamps, filters.	
Non-normal operation: Replacing damaged laser components, gross alignment, new optical systems, amplifier/internal laser alignment, etc..	