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:	Femtosecond Laser System for Surface Chemical Dynamics
Location:	Building 555, Room 353

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: Nicholas Camillone *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.

Chris Weilandics
BNL LSO printed name *Signature* *Date*

Jack Preses
BNL Associate LSO printed name *Signature* *Date*

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

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

APPLICABLE LASER OPERATIONS
☒ Operation ☒ Maintenance ☒ Service ☐ Specific Operation ☐ Fiber Optics

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 Hazard Limits*. 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: Class 4 lasers are *inherently unsafe*. In addition to the hazards of direct, intra-beam viewing, they are capable of producing hazardous diffuse reflections. In addition, they 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	Wavelengths	ANSI Class	Maximum Power or Energy/Pulse	Pulse Length	Repetition Rate
He-Ne	632 nm	2	1 mW	CW	NA
diode-pumped, doubled $Nd:YVO_4$	532 nm	4	5 W	CW	NA
Ti:Sapphire oscillator	710 – 980 nm	4	10 nJ/ pulse	> 50 fs, < 100 fs	80 MHz
doubled Nd:YLF	527 nm	4	10 mJ/ pulse	350 ns	1 kHz
Ti:Sapphire regenerative amplifier	710 – 980 nm	4	1 mJ/ pulse	> 90 fs, < 130 fs	1 kHz

Laser classifications were determined using ANSI Z136.1-2000 Tables 1 and 2, with wavelength correction factors from Table 6. Some examples are in Tables A1 and A2. MPEs are used for determining the OD of laser eyewear for accidental intrabeam viewing. MPEs were calculated using ANSI Z136.1-2000 Table 5a, with wavelength and multiple pulse corrections from Table 6 as necessary, and following the rules in section 8.2.3. To provide for worst-case scenarios, it was assumed that beams matched the maximum ocular diameter for each wavelength in table 8; according to the standard, smaller beams are treated using the maximum ocular aperture as well. Such calculations can be involved; if there is any doubt, please see the owner/operator and/or the LSO listed on the first page of this SOP for assistance.

LASER SYSTEM OCULAR HAZARD LIMITS				
Laser Type	Wavelength (nm)	Intrabeam MPE Limit	Diffuse MPE Limit	Diffuse Viewing Limit
He-Ne	632 nm	6.4×10^{-1} mJ/cm^2	10×10^{-3} J/cm^2	21 mW
diode-pumped, doubled Nd:YVO_4	532 nm	6.4×10^{-1} mJ/cm^2	10×10^{-3} J/cm^2	21 mW
Ti:Sapphire oscillator	710 – 980 nm	13.3×10^{-9} mJ/cm^2	4.8×10^{-9} mJ/cm^2	6 nJ/pulse
doubled Nd:YLF	527 nm	126×10^{-6} mJ/cm^2	18×10^{-6} mJ/cm^2	22.6 μJ/pulse
Ti:Sapphire regenerative amplifier	710 – 980 nm	1.57×10^{-6} mJ/cm^2	564×10^{-9} mJ/cm^2	709 nJ/pulse

Note: The health effects of long term exposure to ultrafast laser pulses may not be fully understood.

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.

L-N_2 used in cryostat in vacuum system for cooling crystal target. Approximate usage during experimental runs – 100 L/month. The L-N_2 is not used in direct connection with any of the lasers.

☒ **Chemicals & Compressed Gasses**

Describe type, quantity, and use.

As described in the Experimental Safety Review for the laboratory, CO-7-3. These are not used in direct connection with any of the lasers with a single exception. Compressed N_2 can be used to purge the Ti:S oscillator and Ti:S amplifier enclosures.

☒ **Electrical Hazards**

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

All lasers have commercial power supplies. Under normal operating conditions, these present no hazard. High currents and voltages are present inside these supplies, and capacitors may hold dangerous energy even when the supply is turned off. Strict adherence to protocols is required if maintenance is required on the laser power supplies. Please refer to the Maintenance Procedures detailed below.

☒ **Other Special Equipment**

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

The laser system is interfaced with a stainless steel UHV / atmospheric pressure reaction chamber as described in the Experimental Safety Review for the laboratory (CO-7-3). The output of either the Ti:S oscillator or the Ti:S amplifier is directed at the surface of crystals mounted either on the same optical table that holds the lasers or within the UHV chamber. Light reflected from the crystal surface is either terminated by a beam stop or collected and directed into spectrum analyzers comprised of filters and/or a monochromator and photomultiplier detector. Optical analytical instruments are fixed on the same optical table that holds the lasers or on the table supporting the UHV / atmospheric pressure reaction chamber.

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)*.

Keys & Controls: The power supplies for the pump lasers (Nd:YVO_4 and Nd:YLF) are enabled by keyed power switches. Both also have remote electronic control boxes. Mode-locking of the Ti:S oscillator can be controlled by a Spectra Physics Model 3955 electronics module. A synchronization and delay generator (SDG) controls the emission of amplified light from the Ti:S regenerative amplifier.

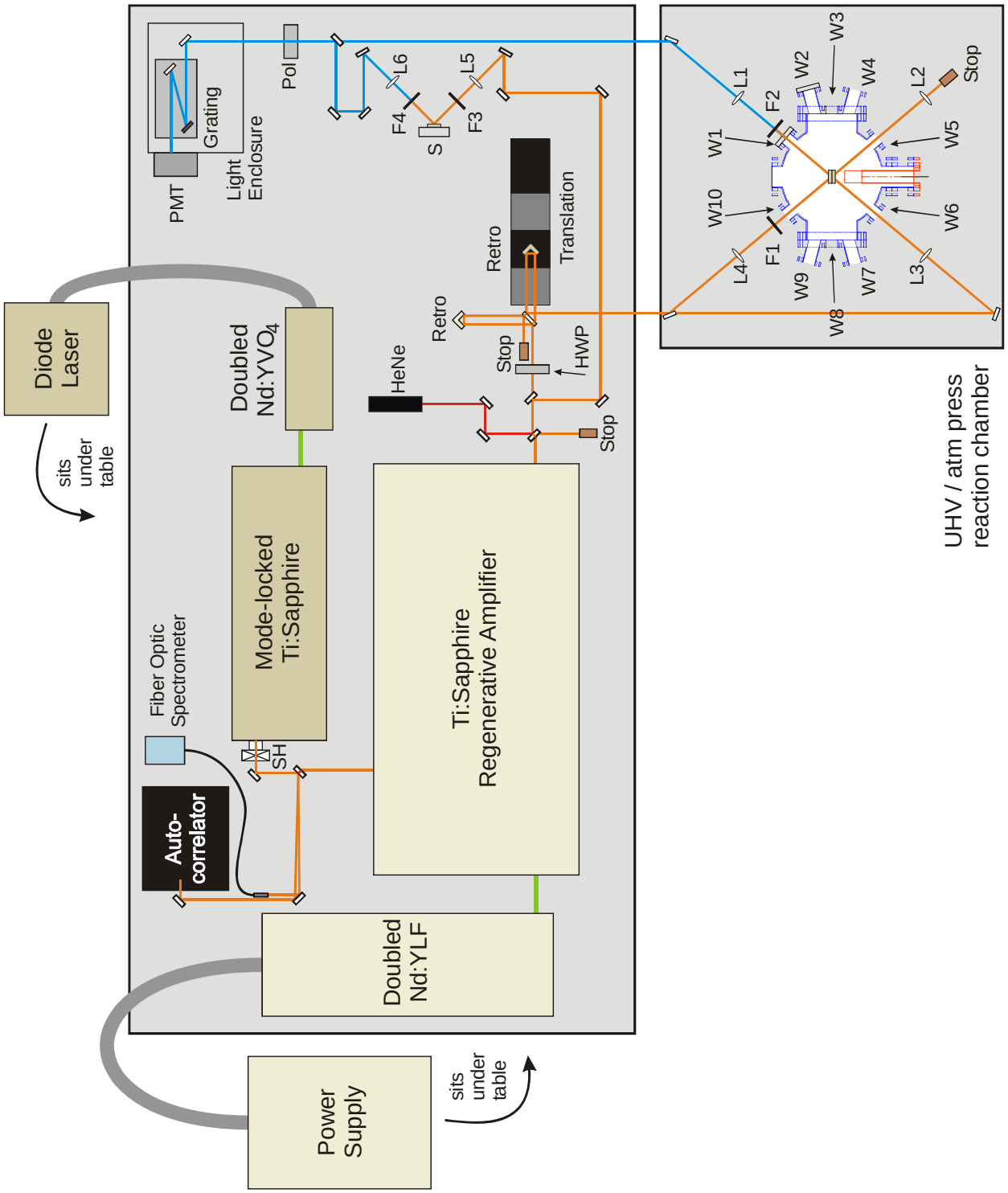
Beam Path: All lasers are operated on a fixed optical table with beams confined to the space above the table top. The single exception is when a beam is directed onto the experimental surface inside the reaction chamber described above and in the Experimental Safety Review for the laboratory. Beams reflected from the experimental surface are terminated by a beam stop or collected and redirected to the optical table for analysis. Propagation of the beam between the table and chamber is restricted to beam heights below 48 inches above the floor level.

The (~ 15 cm long) path of the pump beams between the Nd:YVO_4 and the Ti:S oscillator and between the Nd:YLF and the Ti:S regenerative amplifier are completely enclosed under normal operating conditions.

An experimental block diagram is provided below. *This diagram illustrates one of several possible configurations.* The locations of the Nd:YVO_4, Nd:YLF, Ti:S oscillator, Ti:S amplifier and UHV chamber are fixed. However, the detailed arrangements of the mirrors and diagnostics may vary depending upon the type of experiment being conducted.

Note that the UHV chamber has a total of 10 windows which may serve as entrance or exit ports. Any changes in the laser beam path must account for all possible reflections from the windows and the crystal and crystal holder at the center of the chamber, as well as direct and indirect propagation of light through the chamber. All beams are terminated by power-appropriate beam stops or in diagnostic equipment.

The experimental block diagram can be found on the page following.


Diode Laser
sits under table
Doubled Nd:YVO4
Mode-locked Ti:Sapphire
Fiber Optic Spectrometer
Auto-correlator
SH
Doubled Nd:YLF
Power Supply
sits under table
Ti:Sapphire Regenerative Amplifier
HeNe
Retro
Stop
HWP
Stop
Retro
Translation
PMT
Grating
Light Enclosure
Pol
L6
L5
F4
F3
S
W1
W2
W3
W4
W5
W6
W7
W8
W9
W10
L1
L2
L3
L4
F1
F2
Stop
UHV / atm press reaction chamber

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)

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:

Beam enclosures: During normal operation, lasers are only operated with the covers in place, with laser output only at the labeled apertures. The Nd:YVO_4 and Nd:YLF pump beams are fully enclosed in transit from the pump laser heads to the Ti:S oscillator or Ti:S amplifier. Alignment procedures requiring removal of enclosures are discussed below in the Administrative Controls section.

Actuated Beam Stops / Shutters: The Nd:YVO_4 and Nd:YLF lasers are outfitted by the manufacturer with intracavity shutters. The Ti:S oscillator is equipped with a solenoid-actuated external beam stop/shutter that is activated by the LCA door interlock system. When the interlock is tripped by emergency or unauthorized entry to the laboratory the beam stop blocks the output of the Ti:S oscillator. In addition, the beam stop can be closed by manually de-energizing the solenoid. The beam stop has a “normally closed” or “fail safe” design; i.e. when there is no power provided to it, the shutter is forced closed.

Static Beam Stops: Homebuilt beam stops are used to terminate all Class 3 and Class 4 beams not otherwise terminated by a detector or power meter.

Protective Housing Interlocks: All lasers are fitted by the manufacturer with protective housing interlocks as described in their corresponding manuals. The Ti:S oscillator, Ti:S regenerative amplifier and Nd:YLF laser have manufacturer-installed mechanical cover interlocks that close beam-entrance-port

or intracavity shutters when the enclosure covers are removed. These interlocks may only be defeated for the purposes of alignment within the enclosure as stipulated in the manuals provided by the manufacturer. The 532 nm pump laser has no cover interlocks as it contains no user-serviceable parts; removal of the protective housing requires the use of tools and is not to be performed by anyone other than those trained by the manufacturer (Spectra-Physics).

Activation Warning System: The Nd:YVO_4 and Nd:YLF lasers are outfitted by the manufacturer with illuminated activation indicators. In addition, the LCA door interlock system is equipped with a flashing LASER ON sign, as well as red and green indicator lights located both inside and outside the LCA near the door pushbuttons. These are illuminated when the interlock system is enabled.

Key Controls: The Nd:YVO_4 and Nd:YLF lasers are outfitted by the manufacturer with key controls. Both the Ti:S oscillator, Ti:S regenerative amplifier are passive devices dependant on pump beams and are not keyed.

Emission Delays: Once switched on, the Nd:YVO_4 laser will emit laser radiation only after an emission delay set by the manufacturer. The power button must be depressed once to initiate a temperature stabilization sequence and then depressed a second time for several seconds in order for the laser to initiate emission. During the latter process, the LASER EMISSION light flashes and, when emission begins, remains on to indicate that laser radiation is available if the shutter is open. The Nd:YLF laser requires enabling of the lamp for lasing to become possible. After a short delay, the LAMP ON indicator light illuminates. Pulsed radiation is emitted only after the Q-switch is activated and the internal shutter opened.

Other Interlock: the Laser Controlled Area (LCA) Door Interlock System. All Class 4 lasers are connected to the LCA door interlock system. Emergency or unauthorized entry to the laboratory will prevent laser radiation from leaving the emission ports of all Class 4 lasers in the manner described in the following.

Nd:YVO_4: Laser power supply is connected directly to the LCA interlock. Tripping of the interlock shuts down the power supply to the diodes.

Nd:YLF: Laser power supply is connected directly to the LCA interlock. Tripping of the interlock shuts down the power supply to the flash lamp.

Ti:S oscillator: Laser is equipped with an external solenoid-actuated beam stop. Tripping of the interlock closes the beam stop.

Ti:S amplifier: Emission from the amplifier is dependent upon input from the Nd:YLF and the Ti:S oscillator. Tripping of the interlock disables amplifier emission by shutting down the outputs from Nd:YLF and the Ti:S oscillator.

The LCA door interlock system employs magnetic sensor switches mounted on both doorways of the laboratory to detect entry to the LCA. Controlled access is implemented with pushbutton bypasses at the doors, which allows ~ 25 seconds for *authorized users* to enter or leave the LCA without shutting down the lasers. If the doors are opened without bypass, or held open longer than ~ 25 seconds, emission from all lasers is terminated.

As stipulated in the Administrative Controls Section, during normal operation, the output of the diode pumped-Nd:YVO_4 laser is entirely enclosed. Only under this condition may the relay controlling the power to the diodes be bypassed, and the solenoid-actuated beam stop will guarantee that no laser radiation is emitted into the room if the doors are opened without bypass.

The interlock system is tested every six months, and when a configuration change requires moving interlock cabling, by following a checklist protocol, exercising all components of the interlock system. The interlock circuit design follows the Chemistry Department standard for laser controlled areas, and is attached below. Documentation and inspection records are maintained in the laboratory.

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:

1. Lasers listed in this SOP are operated only in room 353 (of building 555) which has been designated as a Laser Controlled Area.
2. All lasers have mandated labels provided by the manufacturer.
3. Appropriate warning signs and indicators are posted at each entrance. A flashing LASER ON warning light is mounted outside the main (front) entrance. Red and green indicator lights are located near the door pushbuttons both inside and outside the LCA at both the main (front) and service chase (back) entrance. The lights are illuminated whenever the interlock system is activated.
4. *The interlock needs to be activated in order for accessible laser light to be emitted into the LCA.* The laser interlock is wired such that accessible laser light cannot be emitted from any of the Class 4 laser sources unless the interlock system has been activated. Interlock and other hardware shall not be modified so as to defeat this purpose.

Operation SOP:

1. Only *authorized users listed in this document* are permitted to operate lasers in this laboratory.
2. Operation does *not* include gross alignment. Gross alignment may be performed only by those specifically trained and approved by the laser owner/operator. Gross alignment is defined below in paragraph 1 of the Alignment SOP.
3. Users must use good sense in avoiding actions that place themselves or coworkers at risk of laser-related injuries. If at any time a user is unsure of the correct procedure to follow, the user should STOP and seek the advice of the laser owner/operator.
4. Within the Nominal Hazard Zone (NHZ, see point 6 below), eyewear must be worn at all times. Remember that Class 4 laser beams can cause ocular damage even when viewed in diffuse reflection.
5. To reduce accidental reflections, watches, rings, dangling badges, necklaces, and reflective jewelry must be taken off before laser operations begin. Use of non-reflective tools should be considered. All unnecessary equipment, tools and combustible material (if fire is a possibility) are to be removed from the laser table surfaces to minimize the possibility of stray reflections and non-beam accidents.
6. Except during certain gross alignment procedures, all primary and specular beams, and diffuse reflections from Class 4 laser beams must be contained on the laser tables using non-combustible diffusely reflecting or absorbing laser beam stops that do not create hazardous vapors. Beams are diverted off tables (at heights below 48 inches above the floor) only to be directed into the UHV /

atmospheric pressure reaction chamber, and in such case the reflections are directed back to the laser table or terminated by a beam stop. Physical protection must be provided from vertical beams or any other situation where unexpected exposure might occur. Under these conditions, the Nominal Hazard Zone (NHZ) is confined to the space above the laser tables and the UHV reaction system. Eye protection as specified below (in the PPE section) is required for work within the NHZ.

7. All optics must be solidly attached to laser tables so that accidental “bumps” cannot send beams in unknown directions. Likewise, hand held optical devices including mirrors and filters are never to be inserted into the beam.
8. Lasers should be operated at the minimum intensity consistent with experimental requirements.
9. During normal operation, the 532 nm and 527 nm beams must remain entirely enclosed, the covers must remain on all laser enclosures, and the interlocked shutter must be in place at the output of the Ti:S oscillator. If and only if these conditions are met, the interlock relay controlling the pump laser diodes for the 532 nm laser may be bypassed (deactivated) using the bypass switch.
10. Users must know and follow the routine operation instructions for all lasers as described in the manuals provided by the laser vendors.

Alignment SOP:

1. The type of alignment addressed by the procedures in this section is defined herein as gross alignment, namely any operation involving significant deviation of the beam from its previously established path. This specifically includes:
   (1) any insertion or removal of optical components (including mirrors, lenses, and other devices but not including beam stops or power meters) into or from the previously established beam path,
   (2) any alteration of the beam path that may cause the beam to deviate sufficiently so as to miss an optic or target in the previously established beam path, and
   (3) any work within the laser enclosures involving removal of the enclosure covers.
2. Gross alignment may be performed only by those specifically trained and approved by the laser owner/operator, as documented in the training qualifications table below.
3. During gross alignment procedures, only persons immediately involved in the procedure are to be in the laboratory. These individuals must have appropriate training and be listed in this document as authorized laser users.
4. Eyewear must be reviewed to ensure it provides adequate protection against the full intensity of light at all wavelengths present. Eyewear within the parameters and notes established on the accompanying eyewear table must be worn at all times except where detailed in this SOP.
5. There shall be no intentional intrabeam viewing with the eye.
6. Wherever possible, co-axial low power lasers (e.g., HeNe) should be used when practical for alignment of the primary beam.
7. Definite termination of the beam path must be in place before the beam is allowed to propagate.
8. Alignment procedures are always to be performed with the minimum practical laser power levels and repetition rates.
9. Following a new laser beam set-up or change in alignment, a survey of the unenclosed beam path will be conducted to verify that all unwanted beams and reflections have been properly terminated. An IR viewer shall be used to trace all NIR and IR reflections. Opaque barriers will be used to confine low intensity stray reflections and scattered light to the optical tables. Any unwanted primary or specular beams will be terminated in a beam stop that does not produce hazardous diffuse reflections.
10. Gross alignment of beams from Class 4 lasers into the UHV chamber, Ti:S laser enclosures or experiments on the optical table should be done with beams attenuated as far below Class 4 thresholds as possible, with eye protection adequate for the beam in use. Provided that the beams are attenuated below the diffuse viewing limit (see the Laser System Ocular Hazard table above), and any specular beams are fully controlled, the laser path may be visualized by placing a matte-finished hand-held white card or paper in the path and viewing the diffuse reflection with the laser eyewear *momentarily* removed. This shall be done only by personnel authorized for alignment procedures. It is

important to understand that even when viewed in diffuse reflection, ocular damage can result from momentary unprotected viewing of Class 4 or prolonged viewing of lower intensity laser radiation. In addition, specular or intra-beam viewing of lasers emitting radiation at Class 3b levels will likely cause ocular damage. At no time should any hand-held reflective instrument be placed in the beam.

11. Routine laser-specific alignment procedures may be simple or complex. In either case, specific procedures are outlined in the operation and alignment manuals supplied by the manufacturers, and they must be followed. If at any time an alignment-authorized user is unsure of the correct procedure to follow, the user should STOP and seek the advice of the laser owner/operator.
12. During alignment when any of the following conditions are true, the interlock relay controlling the 532 nm pump laser diodes MUST be active (i.e., interlocked via the interlock system to the laboratory entrance sensors such that unauthorized entry causes the laser power supply to the diodes to shut down):
    (1) the 532 nm pump laser beam enclosure is removed,
    (2) the cover of the Ti:S oscillator enclosure is removed, OR
    (3) the Ti:S oscillator output shutter is in any way disabled.
13. Alignment of the visible (green) pump beams into the either of the Ti:S enclosures is particularly hazardous due to the presence of Class 4 radiation both in the green and the NIR. Alignments must be performed in accordance with the laser user manuals. Full protection against beams at all wavelengths involved must be worn, and an IR viewer shall be used to visualize the NIR beams.
14. Normal laser hazard controls shall be restored when the alignment is completed. Enclosures, covers, beam blocks and barriers must be replaced, and affected interlocks checked for proper operation.

Other Maintenance SOP

1. Relatively little routine maintenance is required for the above described laser system. Procedures such as optics cleaning and/or replacements are to be conducted in strict accordance with the methods described in the user's manuals provided by the manufacturers, and only by individuals with appropriate training who are listed in this document.
2. The Nd:YVO_4 laser requires no routine alignment or maintenance. There is no reason to remove the outer cover as there are no serviceable parts inside the laser head. Only those diagnostics detailed in the Troubleshooting Guide of the user's manual may be performed. Other procedures must be performed by a Spectra-Physics technician or under the strict guidance of a Spectra-Physics service representative.
3. The Nd:YLF laser periodically requires flashlamp replacement, cavity alignment and replacement of the deionization filter. These are to be performed in accordance with the procedures detailed in the manual supplied by the laser manufacturer (Spectra-Physics) and this SOP.
4. Routine maintenance for the Ti:S oscillator includes cleaning and realigning of optics, which requires removal of the laser cover. This may be done only in strict accordance with the procedures outlined in the user's manual and this SOP.
5. Routine maintenance for the Ti:S regenerative amplifier includes cleaning and realigning of optics, which requires removal of the laser cover. This may be done only in strict accordance with the procedures outlined in the user's manual and this SOP.
6. Non-routine maintenance and troubleshooting is a serious matter, as injury or damage to equipment could result from actions taken in unfamiliar circumstances. Non-routine maintenance includes any repairs of the lasers not outlined in the user's manuals. 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 laser manual, or in consultation with the manufacturer's service engineering staff. In no case is "working hot" on power supplies permitted. When there is any uncertainty about the safety of a diagnostic procedure, do not attempt 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.

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.

Laser Enclosure Covers:

must be in place during normal operation. They may be removed temporarily for alignment.

☐ **Nd:YLF**

☐ **Ti:S oscillator** _____ *Important!: When this beam enclosure is removed, the interlock relay controlling the Nd:YVO_4 laser must be enabled.*

☐ **Ti:S amplifier**

Beam Enclosures:

must be in place during normal operation. They may be removed temporarily for alignment.

☐ **Nd:YVO_4 output**_____ *Important!: When this beam enclosure is removed, the interlock relay controlling the Nd:YVO_4 laser must be enabled.*

☐ **Nd:YLF output**

Actuated Beam Shutter:

must be in place and enabled during normal operation.

☐ **Ti:S oscillator output**_____ *Important!: When this shutter is removed or disabled, the interlock relay controlling the Nd:YVO_4 laser must be active.*

Beam stops and optical components on both the main optical bench (table) and the UHV chamber bench are subject to frequent changes in configuration on a daily basis. *The user should never assume that all beams are confined within the NHZ described in the SOP*; rather the beam path and absence of stray reflections must be confirmed each day upon initial start up as well as subsequent to any changes in the configuration. These confirmations shall be performed prior to and after allowing the beam to propagate through the full optical train by:

(1) referring to the laboratory notebook to check for recent modifications to the optical train,
(2) surveying the expected beam path to confirm that it is clear of obstructions,
(3) surveying the expected beam path to confirm that optics are secured to the optical bench and in good condition,
(4) using beam stops to sequence beam propagation through subsections of the optical train, AND
(5) checking for stray reflections after the laser is first allowed to propagate through the optical train.

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.

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.

Preventative Precautions:
During normal operation, for deep red or invisible IR (~ 700 nm or greater) beams, eye protection against the full beam must be worn at all times within the NHZ defined in the Operation SOP above. Once the IR beam path has been established and all beams are fully enclosed or the absence of stray reflections has been carefully confirmed by means of an IR viewer, standard polycarbonate safety glasses may be worn *outside* the NHZ provided *all* personnel remain *outside* the NHZ. Under these conditions, *no adjustments to any of the beams are to be made*.

For the 532 nm and 527 nm beams, eye protection against the full beam must be worn during gross beam alignment. During alignment procedures, beam position may be checked and the laser path may be visualized by placing a matte-finished hand-held white card or paper in the path and viewing the diffuse reflection *momentarily* with the unprotected eye provided that the beams are attenuated as far below the diffuse viewing threshold (see chart) as practicable, and any specular beams are fully controlled. During normal operation the 532 nm and 527 nm beams are to remain *fully enclosed* and eye protection against this wavelength is not required.

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 REQUIREMENTS					
Laser System Hazard	Wavelength (nm)	Calculated Intra-beam Optical Density	Diffuse Optical Density*	NHZ** (meters)	Appropriate Eye Wear***
He-Ne	632 nm	NA	NA	NA	NA
diode-pumped, doubled Nd:YVO_4	532 nm	3.7 (0.25 sec.)	2.4	3.1 m	1, 3
Ti:Sapphire oscillator	710 – 980 nm	3.3 (10 sec.)	0.2	0.26 m	2, 3, 4
doubled Nd:YLF	527 nm	5.3 (0.25 sec.)	2.7	4.2 m	3
Ti:Sapphire regenerative amplifier	710 – 980 nm	6.2 (10 sec.)	3.15	7.5 m	3, 4‡

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

**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 provided the optical densities are equivalent or greater than those required.

EYE WEAR SPECIFICATIONS					
Laser System Eyewear Identification				Wavelengths (nm)	Optical Density
#	Model	Type	Color		
1	Cascade Laser Corp, Ar Ion	Polycarbonate wrap	Orange	190–375	5+
				375–532	4+
				10600	6+
2	Glendale Laser-Gard, NdGa:YAG	Polycarbonate wrap	Green	190–420	9+
				770–810	5+
				810–1100	7+
				1064	10+
				5000–11000	7+
3	Trinity, Glass Filter 1126	Spectacle	Brown	190-540	6+
				632	2+
				650-690	3+
				690-710	6+
				710-1200	8+
				10,600	5+
4	Trinity, Polycarbonate Filter 1205	Spectacle	Amber-Pink-Brown	190-375	5+
				730-855	4+
				755-840	7+
				10,600	6+

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. Only persons who have signed below and been authorized by the Owner/Operator may operate the lasers covered by this SOP. 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.

User Printed Name	Signature	Date	Owner/Operator Signature
Owner: Nicholas Camillone	———		
Paul Szymanski			