LASER CONTROLLED AREA STANDARD OPERATING PROCEDURE (SOP) CO_2 LASER SYSTEM

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: PITER I – Picosecond Tearawatt CO2 Laser System
Location: Rooms C1&C2, Accelerator Test Facility, Bldg 820

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: Igor Pogorelsky	*Signature:*	*Date:* 2/17/11

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 Welsh *BNL LSO printed name*	*Signature*	2/16/11 *Date*
Michael J. Zarcone *Department ESH Coordinator printed name*	*Signature*	2/11/11 *Date*
T. Ludlam *Department Chair/Division Head printed name*	*Signature*	2/16/11 *Date*

APPLICABLE LASER OPERATIONS
☒ Operation ☒ Maintenance ☒ Service ☐ Specific Operation (specify)

RELATIONSHIP TO OTHER DOCUMENTS

Specifically name other documents, (such as ESRs, SADs/SARs, other SOPs) that describe hazards present in the Laser Controlled Area outside the scope of this document.

ESRs: PO2009-099, PO2009-208, PO2009-212

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 system characteristics necessary for eyewear calculations and NHZ analysis are described along with the results in the PPE section of this document.

LASER SYSTEM CHARACTERISTICS

Laser Type *(Argon, CO_2, etc.)*	Wavelength(s) (nm)	ANSI Class	Maximum Power or Energy/Pulse (W or J)	Pulse Length (s)	Repe-tition Rate (Hz)	Beam Dia-meter (mm)
CO2 oscillator	10,000	4	100 mJ/pulse	100 ns	1	4
CO2 preamlifier	10,000	4	100 mJ/pulse	10 ns	0.2	8
CO2 regenerative amplifier	10,000	4	100 mJ/pulse	3-200 ps	1	4
CO2 final amplifier	10,000	4	30 J/pulse	3-200 ps	0.03	50
Nd:YAG	1064	4	40mJ	14ps	3	6
Nd:YAG	532	4	5mJ	1-10ps	3	6
(Alignment only)						
HeNe (05-LHR-991)	632	IIIB	30mW	CW	CW	3
HeNe (1125)	632	IIIB	30mW			3
HeNe (05-LHR-151)	632	IIIB	15mW			3
HeNe (105-2)	632	IIIA	10mW			3
HeNe (LSR2R)	632	IIIB	25mW			3
HeNe (1144)	632	IIIB	30mW			3
HeNe (GLG5800)	632	IIIB	100mW			5

Applicable Laser Operations:
Describe the scope of the work to be done, and how the laser system is used. Provide information regarding unusual circumstances necessary for evaluation of hazards by the LSO not provided elsewhere in this document (e.g.: laser beams entering other equipment such as vacuum chambers & microscopes or propagated into unexpected places/directions).

The CO_2 laser system is used for user's experiments set at the Experiment Hall or FEL room. Delivery of the laser beam to each room is controlled by the ATF Laser Interlock Procedure. Specifics of each use is described in the corresponding ESR. Switching between experiments does not involve changing the laser configuration which is described in the next section.

Laser System Configuration:
Describe the laser beam path for fixed components of the system, and provide a functional/block diagram for complicated beam paths. Photographs may be used where they convey sufficient information. Note that Engineering Controls are described in a separate section below.

Detailed block –diagram of the ATF CO_2 laser system is depicted in three drawings (Attachment A).

Identify hazards mitigated or created by the placement, movement, and/or status of components. 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).

Every application of the ATF CO_2 laser system, including user's experiments or just using diagnostic, includes preliminary setup with HeNe lasers pre-aligned to the CO2 beam path. The set up is finalized using a low-power CO_2 beam (~1000 times smaller energy than the real beam). At this stage, we ensure that any additional components are removed and the beam is delivered to the experiment. This way, any potential for misdirecting the output laser beam is practically eliminated.

For specific *laser-related* hazards below, provide details (types, quantities, use) as appropriate. Details of non-laser related hazards should be cross-referenced to the other documents cited above.

☒ **Cryogen Use**

Several liters of LN2 in two vacuum traps

☒ Chemicals & Compressed Gases

CO2 laser oscillator, preamplifier, and amplifier are supplied with CO2, N2, He gases from high-pressure cylinders located outside the laser rooms. The greatest gas consumption is in the amplifier: 1 m3 of the CO2:N2:He mixture (90% of this He) pressurized up to 116 psig. To eliminate the possibility of accidental gas release to the laser room that may result in oxygen defficiency, the amplifier is equipped with emergency exhaust relief lines to vent gas to the outside. Conventional cleaning solvents in small plastic bottles (alcohol. acetone, stored in a secondary containment in a cabinet outside the room).

SF6: used to fill PFN of laser amplifier HP-5 (SDI) to 1.3 atm, volume 300 liter, one-time charge, normally need to add 0.1 atm monthly due to leakage. Ultimately, will be pumped to atmosphere if access inside PFN is necessary. 10-liter SF6 cylinder is stored in C1 room.

Freons: Several lecture bottles are connected to a mixing manifold in C2 room. Freon mixture includes: C4F8 (HC-318), FC-12, FC-1113, FC-115.
Mixed to certain proportion prescribed in literature, freons are filled into a optical cell with a volume of ~10 ml at up to 100 torr pressure absolute. A filled cell is used as an optical filter placed in the CO2 laser beam path. Freons do not degrade during operation or storage in the cell which normally does not require a periodical refill. Mixing manifold, as well as an optical cell after use, are pumped out with a vacuum pump which is vented to atmosphere.

☒ Electrical Hazards

DC power supplies with the maximum capacity of 1.5 kW, 120 kV. Up to 1 MV of pulsed voltage in pulse forming network and at the laser electrodes.

☒ Other Special Equipment

Equipment used with the laser[s] that may introduce additional hazards.

All the optical diagnostics equipment, such as: energy meters, IR cameras, Spectrometers, Streak camera, optical diodes, can not handle the full laser output and should be used with a proper attenuation. Failure to apply attenuation may result in damage of the equipment or its components. However, this does not create additional hazards to the personel.

DESCRIBE CONTROLS

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 Z136.1-2007)

BNL SBMS Sections:

Laser Safety Subject Area
Electrical Safety Subject Area: Interlock Safety For Protection Of Personnel

ENGINEERING CONTROLS

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

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 by the LSO/ALSO and the LESO, a copy of the design review documentation and written testing protocol must be on file. Completed periodic interlock testing checklists should be retained to document the testing history.**

Engineering Controls Description:

Beam Enclosures: PITER I laser components and transport paths are entirely screened by pipes or flat panel enclosures.
Beam Enclosure Interlocks: To prevent unauthorized removal of beam enclosures and access to laser radiation, laser rooms are equipped by safety interlock system. This system, its testing procedure and checklist are documented in attachments. In addition, parts of the optical transport system that may contain laser radiation when a room is not interlocked are padlocked.
Beam Stops: Optical shutters located at any laser beam exit from a laser room serve as beam stops. They are operated using safety interlock and logic control units.
Key Controls: Key controls are installed into all critical control functions operation of which may result in release of the laser radiation or in high-voltage, high-current hazards. These include primarily: high-voltage power supplies for the laser equipment and laser safety shutter interlocks.

Activation Warning System: Illuminated warning signals are activated whenever a laser room is interlocked. Intermittent audio warning signals additionally alert a laser operator about activation of safety interlock or opening a laser shutter.
Protective Housing Interlocks: oscillator enclosure is equipped with end switch to prevent exposure to HV components (other HV power supplies are protected with padlocks).

A detailed description of the engineering controls and procedures are given in the following documents: ATF Handbook Sections 1.3.3 "ATF Laser Interlock System" and 1.3.5 "Test Procedure for ATF Laser Interlock Systems".

Also, see existing documentation PO-P-ATF-0001 "Inspection Procedure for CO2 TeraWatt Laser Amplifier Pressure Vessel", and Appendix D "Maintenance procedure".

ADMINISTRATIVE CONTROLS

☒ Laser Controlled Area ☒ Signs ☒ Labels ☐ Operating Limits

Class 3b and 4 lasers are required to be operated in Laser Controlled areas with appropriate warning signs and labels. 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 at least indicating the system's wavelength and power. Required labels must remain legible and attached. The manufacturer should label commercial systems.

Describe administrative operational limits (*e.g.*, requirements to operate at reduced power) if appropriate.

Signs & labels: In addition to laser door interlocks, all doors to CO2 rooms have "DANGER – LASER" signs that conform to BNL ESH standards. All lasers have vendor-specific labels. PPE are located in the vestibule outside of the C2 room.
See Appendix B for safety guidelines for laser alignment

Standard Operating Procedures (SOPs) are required for Class 3B and Class 4 laser system operation, maintenance/servicing and laser alignment. The SOPs need only contain the safety information necessary to perform these tasks and identify appropriate control measures including postings (showing required ODs for eyewear and ANSI hazard class) and any additional personal protective equipment required. 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.

Operation:

Describe controls for routine use and adjustments of laser system(s).

Operating procedure is described in Appendix C

Maintenance/Service:

Describe additional controls required to maintain laser operation. May or may not require beam access. Follows manufacturer instructions where appropriate. Routine maintenance: replacing consumables (flashlamps, gases, dyes, *etc.*) Non-routine service: Less frequent: Replacing damaged components, diagnostics, *etc.*

Outside service personnel.
Indicate how outside service personnel are trained and supervised. Work performed by outside service personnel is planned according to the *Work Planning and Control* SBMS subject area and regulated by the *Guest and Visitors* SBMS subject area.

See Appendix D "Maintenance Procedure"
Also, see existing documentation PO-P-ATF-0001 "Inspection Procedure for CO2 TeraWatt Laser Amplifier Pressure Vessel"

Alignment:

As most laser accidents occur during alignment, provide a description of routine procedures where appropriate and controls to mitigate the hazards. For non-routine procedures, provide a safety envelope necessary to protect workers. This includes activities such as initial system/experimental alignment.

Alignment procedure is described in Appendix B.

Laser system configuration changes:

Changes to the laser system can result in new concerns about safety or damage to equipment. Describe how changes are communicated between coworkers (e.g.,*: lab notebooks, logs, whiteboards).*

a) Presently, I. Pogorelsky is the only designated operator of the CO2 laser system. Therefore the need for communication is limited.
b) Any changes in operating conditions or components are reported at the ATF's weekly meetings.
c) Permanent changes in configuration shall be introduced into updated schemes attached to this form and Alignment Procedure document.
d) For any temporary changes in configuration, a warning sign is posted in the affected area.

PERSONAL PROTECTIVE EQUIPMENT

Skin Protection: If the potential exists for damaging skin exposure as determined by the LSO (particularly for UV lasers 295-400 nm or welding/cutting applications), describe the hazard(s) and the method(s) used for mitigation. Skin-covers and / or sun-screen creams are recommended.

1. No skin protection is required during the system alignment conducted with at low laser intensity (final amplifier off).
2. Full power laser beam may cause minor skin damage. However, it is localized inside laser enclosures and within optical table area where no personal present during full-power laser shots.

Eyewear: 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. 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 circumstances and the precautions that will be taken to prevent eye injury.

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.

Most accidents occur during alignment. Extra care must be taken during alignment. Eyewear must be worn during alignment, but it must be remembered that eyewear is NOT the first level of laser safety. Eyewear protects the wearer only when all other safety procedures and equipment have failed. Better protection is provided by careful consideration of procedures and proper beam management.

LASER SYSTEM CHARACTERISTICS

Laser Type *(Argon, CO_2, etc.)*	Wavelength(s) (nm)	ANSI Class	Maximum Power or Energy/Pulse (J or W)	Pulse Length (s)	Repe-tition Rate (Hz)	Beam Dia-meter (mm)
CO2 oscillator	10,000	4	100 mJ/pulse	100 ns	1	4
CO2 preamlifier	10,000	4	100 mJ/pulse	10 ns	0.2	8
CO2 regenerative amplifier	10,000	4	100 mJ/pulse	3-200 ps	1	4
CO2 final amplifier	10,000	4	30 J/pulse	3-200 ps	0.03	50
Nd:YAG	1064	4	40mJ	14ps	3	6
Nd:YAG	532	4	5mJ	1-10ps	3	6

EYEWEAR REQUIREMENTS

Laser System Hazard	Wavelength (nm)	Calculated Intra-beam Optical Density	Diffuse Optical Density*	NHZ** (meters)	Appropriate Eye Wear***
CO2 amplifier	10,000	2.3	4	NA	UVEX L99-LS535 GU2-KG5-OG570 UVEX LOTG-CO2
CO2 preamplifier	10,000	2.9	5	NA	UVEX L99-LS535 GU2-KG5-OG570 UVEX LOTG-CO2
CO2 regen. amplifier	10,000	2.9	5	NA	UVEX L99-LS535 GU2-KG5-OG570 UVEX LOTG-CO2
CO2 oscillator	10,000	3	5.2	NA	UVEX L99-LS535 GU2-KG5-OG570 UVEX LOTG-CO2
YAG laser radiation	1064	5.7	2.7	4.4	UVEX L99-LS535 GU2-KG5-OG570
YAG 2nd harmonic	532	6	3.3	8.9	GU2-KG5-OG570

EYEWEAR SPECIFICATIONS

Laser System Eyewear Identification***	Wavelengths	Optical Density
UVEX L99-LS535 (white spectacles with bluish-green lenses)	10.6 µm 1.06 µm	4 5
GU2-KG5-OG570 (blue goggles with clear glass plate and orange glass plate in flip-up)	10.6 µm 1.06 µm 0.53 µm	>7 >7 >5
UVEX LOTG-CO2 (clear plastic spectacles)	10.6 µm	5

* 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.

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 must receive a baseline medical surveillance eye examination, documented in the Occupational Medicine Clinic before using lasers. Owners/Operators and Qualified Laser Operators must complete the awareness level BNL online 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.

Appendix A
Optical Diagrams

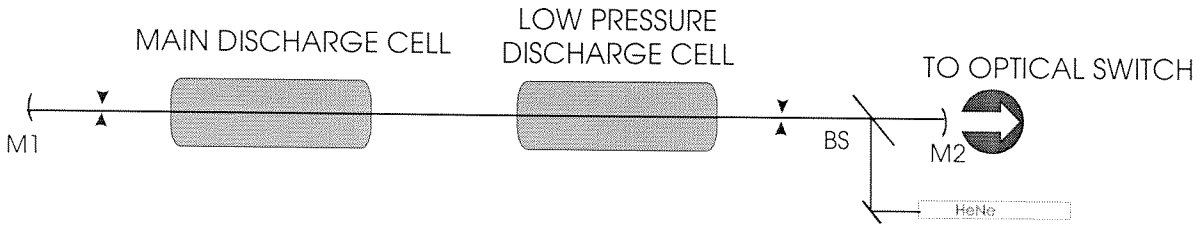

FIGURE 1

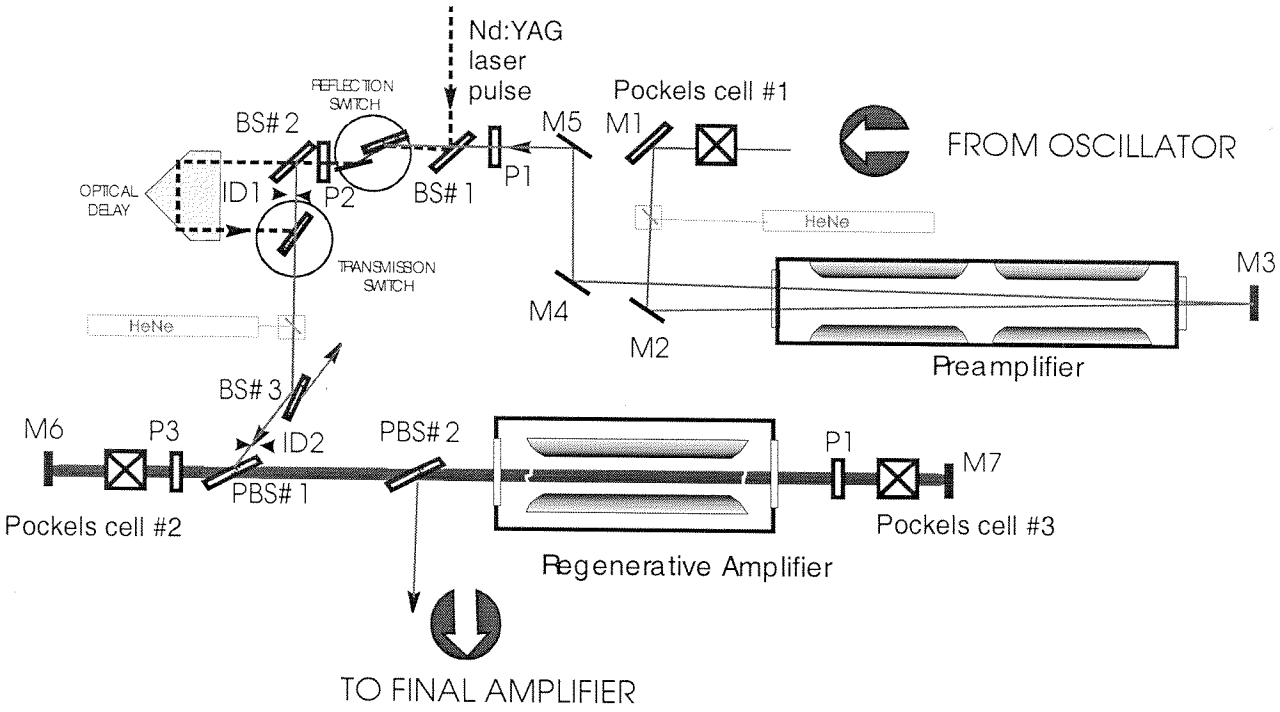

FIGURE 2

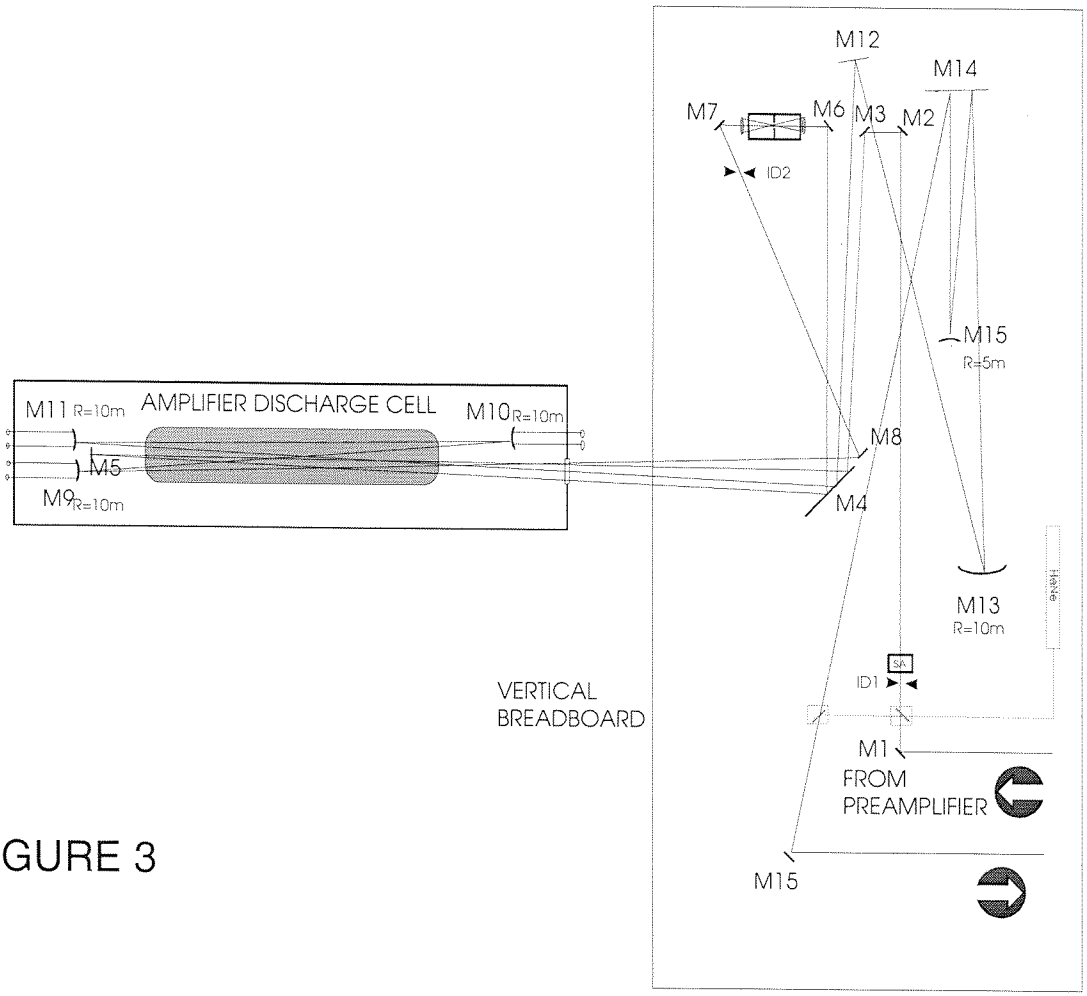
M12
M14
M7
M6
M3
M2
ID2
M15
R=5m
M11 R=10m
AMPLIFIER DISCHARGE CELL
M10 R=10m
M8
M5
M9 R=10m
M4
M13
R=10m
SA
ID1
VERTICAL
BREADBOARD
M1
FROM
PREAMPLIFIER
M15

FIGURE 3

Appendix B
Alignment Guidelines

Procedural Considerations

1. To reduce accidental reflections, watches, rings, dangling badges, necklaces, reflective jewelry are taken off before any alignment activities begin. Use of non-reflective tools should be considered.
2. Access to the room/area is limited to authorized personnel only.
3. All unnecessary equipment, tools, have been removed to minimize the possibility of stray reflections and non-beam accidents.
4. Persons conducting the alignment have been authorized by the RI

Alignment Methods to be used for this laser

1. Laser Protective Eyewear shall be worn at all times during the alignment, within the parameters and notes established on the accompanying laser table.
2. There shall be no intentional intrabeam viewing with the eye.
3. Co-axial low power HeNe lasers should be used when practical for alignment of the primary CO2 beam.
4. Reduce the beam power through the use of filters, beam splitters and dumps, or reducing power at the power supply. Avoid the use of high-power settings during alignment as much as is practical.
5. The LSO has authorized reduced optical density eyewear to allow the beam spot to be seen. Measures shall be taken and documented to ensure that no stray hazardous specular reflections are present before the lower OD eyewear is worn. A return to the Maximum OD eyewear as listed in the laser table will be made when the alignment is complete. The eyewear is labeled as alignment eyewear and is stored in a different location than the standard laser eyewear for this operation.
6. Beam Control- the beam is enclosed as much as practical, the shutter is closed as much as practical during course adjustments, optics/optics mounts are secured to the table as much as practical, beam stops are secured to the table or optics mounts.
7. Any stray or unused beams are terminated.
8. Pulsed lasers are aligned by firing single pulses when practical.
9. Normal laser hazard controls shall be restored when the alignment is completed. This includes enclosures, covers, beam blocks/barriers have been replaced, and affected interlocks checked for proper operation.

APPENDIX C
ATF CO_2 LASER SYSTEM
Operations: turning the system on and off

WARNING: An authorized operator only can operate the ATF CO_2 laser system. A list of qualified ATF CO_2 laser operators is posted in the ATF Control Room and in the ATF CO_2 Laser Room C2. Appropriate laser safety goggles certified for PITER I laser shall be worn all the time when rooms C1 and C2 are interlocked, lasers are powered, and laser interlock shutters are activated.

TURNING THE SYSTEM ON

1. Prepare interlock system

1a. Verify that CO_2 rooms are secure by checking a status indicators on the MCR laser interlock panel in room C2. If not secured, follow the search and secure procedures for the rooms as specified in the PO-P-0026.

1b. Obtain the CO2 LASER SHUTTER KEY (#5) and YAG TO CO2 KEY (#3) from the key box in the Control room. Sign out the keys in the key log book.

1c. Insert the keys into the appropriate locks on the MCR laser interlock panel in room C2.

2. Prepare equipment

2a. Fill the amplifier discharge cells with gas according to specifications, start gas circulation through the oscillator. Fill spark gaps of the amplifier PFN's with synthetic air or SF_6 gas according to the labeling on the gas distribution panels.

2b. Turn alignment HeNe lasers on. Turn the CO_2 oscillator on (see 3). Align the CO_2 oscillator beam path through the system and YAG laser beam on the semiconductor switch according to the CO_2 Laser Alignment Procedure (ATF-0016).

2c. Turn AC power switches on control and diagnostic equipment. Allow 10 min to warm up.

3. Turn oscillator on

3a. Make sure that the oscillator main discharge cell is filled with the fresh gas and gas circulates through the smoothing tube at >10 torr pressure.

3b. Turn HV switches on the oscillator control panel on, set the main discharge voltage.

3c. Start pulse/delay generator triggering at the preset repetition rate or use a trigger button.

3d. Monitor the output pulse energy using a joulemeter. Set the energy at the desirable level by adjusting the discharge voltage and intracavity iris opening.

3e. Using a photon drag detector and an oscilloscope observe the shape of the laser pulse. Adjust the PZT voltage to eliminate ripples in the laser pulse envelope.

4. Turn slicer on

4a. Open YAG shutter. Check that the YAG beam overlaps with the He-Ne beam on the semiconductor switch.

4b. With turned on CO_2 oscillator, open the CO_2 shutter and observe on the scope position of the CO_2 and YAG pulses. Using delay pulse generator, adjust the oscillator delay for synchronization with the first YAG pulse.

4c. Use IR card to observe spatial overlap between the YAG and CO2 beam just in front of the semiconductor switch. On a scope, observe optical switching at the maximum of the CO_2 pulse.

4d. Place a fast detector after the transmission switch and observe a typical sliced laser signal. Adjust YAG/CO2 overlap on the transmission switch to minimize the signal at the "zero" optical delay.

5. Turn preamplifier on

5a. Make sure that the preamplifier discharge cell is filled with gas and air flows through the PFN and the trigger pulser spark gaps.

5b. Turn on krytron box and a trigger pulser for the UV preionization and main discharge triggering, correspondingly.

5c. Turn on trigger generator for the 10 ns gating Pockels switch.

5d. Turn on DC power supplies for preionizer and main discharge and set the required voltage.

5e. Trigger preamplifier with a push button observing typical scope traces from the prionizer and the main discharge.

5f. With turned on oscillator and slicer observe an amplified 10 ns laser pulse and a dip on it due to semiconductor switching.

6. Turn regenerative amplifier on

6a. Turn on the key on the control panel. Check gas and voltage displays. Make adjustments according to manual.

6b. Initiate turn on sequence on the laser PC (takes 10 min).

6c. Turn on HV power supplies for regenerative Pockels switches.

6d. Allow "continuous" triggering for 30 sec. Switch triggering to "external" after observing a uniform discharge without arcs.

6e. With turned on oscillator, slicer and preamplifier observe on a scope a train of laser pulses in the regenerative cavity and a single pulse extracted from the regenerative cavity. Adjust time delays and iris diaphragms inside the regenerative cavity if necessary.

7. Turn final amplifier on

7a. Make sure that the amplifier discharge cell is filled with gas, spark gaps are filled with a synthetic air, and x-ray preionizer is under vacuum.

7b. Turn on AC power switches for power supplies and pulse generators at the control rack.

7c. Start triggering of the preionizer. Upon observation of a stable preionizer operation and typical current/voltage plots turn on the Marx generator.

APPENDIX D
ATF CO_2 LASER SYSTEM
Maintenance Procedure

Recommended procedures at approximate intervals

1. Deionized water in the sharpening capacitor tank cleaning or refill — 1 thousand shots
2. Spark gaps cleaning or replacement — 10 thousand shots
3. Cleaning or refill of transformer oil in transmission line — 10 thousand shots
4. Vacuum pump servicing — every 2 years
5. Regenerative amplifier SDI — refer to the manufacturer's maintenance manual

1. Amplifier vessel inspection

1a. Inspect the internal welds in the amplifier vessel every time when the vessel is open or at least semiannually.

1b. Arrange for liquid dye penetration test if the visual inspection or change in the vacuum condition indicate a possibility of a crack or other defect developed.

2. Deionized water in the sharpening capacitor tank cleaning or refill procedures

2a. Deionized water cleaning can be performed on line while the CO_2 amplifier is in operation by turning on a pump that circulates water through the built-in deionizer.

2b. Deionized water refill

Attention: This procedure requires initial LOTO of the amplifier AC power supply panel

2b.1 After every 1000 shots of the amplifier take sample of the water from the PFN tank.

2b.2 Measure resistivity of the sample water – normally shall be above 50 Mohm mm^2/cm.

2b.3 At a low resistivity, circulate the PFN water through the built-in deionizer.

2b.4 If circulation through the deonizer does not restore the resistivity, proceed to refilling.

2b.5 Attach water pump and exhaust tubing to the valve at the bottom of the PFN water tank.

2b.6 Open the valve, turn the pump on and empty the tank outside the building, close the valve when done.

2b.7 Fill the tank with fresh water from drums (the same water pump can be used after cleaning).

3. Spark gaps cleaning or replacement

3a. Amplifier and preamplifier spark gaps cleaning or replacement

Attention: This procedure requires initial LOTO of the AC power supply

3a.1 Stop air circulation, close air cylinder and regulator, relieve air pressure in the line down to 1 atm.

3a.2 Open the preamplifier PFN enclosure top lead, use grounding pole to make sure that no residual electrical potential exists on the exposed high voltage contacts.

3a.3 Using an oil pump and empty transformer oil from the PFN into clean plastic canisters below the spark gap level.
3a.4 Use grounding pole to make sure that no residual electrical potential exists on the exposed high voltage contacts, disconnect spark gaps from electrical leads and air lines, mark all disconnected wires and terminals to restore the connections upon assembly, ground high voltage terminals.
3a.5 Remove spark gaps from the PFN and entirely clean the oil from the surface.
3a.6 Disassemble and open each spark gap and examine for a possible damage by discharge or pressure and contamination by oil, discharge products, or other debris.
3a.7 Clean internal surfaces of spark gaps using conventional cleaning solvents (alcohol, acetone, etc.) and by sending the metal surfaces if necessary.
3a.8 Assemble spark gaps (or use new), restore connections, fill PFN with oil.
3a.9 Open air cylinder and regulators, bring the air pressure in spark gaps to the required level, visually inspect for bubbles.
3a.10 Restore electrical connections, restore PFN enclosure.
3a.11 Remove LOTO tag from the preamplifier AC power supply panel.
3a.12 Before turning on high voltage, check that the PFN enclosure interlocks work properly.
3a.13 Test PFN functioning at the nominal voltages.

4, Cleaning or refill of transformer oil in transmission line between Marx generator and water capacitor

4a. When the amplifier is in operation, use a pump to circulate the oil in the transmission line after every 100 shots or once a day (whatever comes first).

4b. Change the oil in the transmission line when the oil changes color or after 10 thousand shots (whatever comes first). Procedure for oil change is as follows:
4b.1 Connect container with fresh oil (5 liters or more) to expansion cylinder; make sure that there are no trapped air bubbles in the expansion cylinder and connecting tube left.
4b.2 Disconnect the oil pump return line from the expansion cylinder before the valve; put the end of the return line into the container for spent oil.
4b.3 Start oil pump; continue pumping oil from the fresh oil container through the transmission line watching that no air bubbles are introduced.
4b.4 Stop pumping the oil when the required amount is flashed and the oil running from the return pipe is transparent.
4b.5 Disconnect the fresh oil container from the expansion cylinder.
4b.6 Connect the return line to the expansion cylinder; turn oil pump intermittently several times until air bubbles stop to appear.

5. Vacuum pumps servicing

5a. Periodically check the oil level and color in vacuum pumps.

5b. When necessary, or once in two years send pumps for servicing.