

<b>Brookhaven National Laboratory</b>	<b>Number:</b> ESH-0002	<b>Revision:</b> 03
	<b>Effective:</b> 04/04/01	<b>Page 1 of 20</b>
<b>Subject: Laser Safety Program Documentation</b>		

**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.

<i>System description: 20 Watts CW/pulse fiber-coupled semiconductor diode laser</i>
<i>Location: AGS A3 beamline for E951 experiment</i>

**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.

<b>Owner/Operator:</b>		
<i>Name:</i> Kirk McDonald (Princeton)	<i>Signature:</i>	<i>Date:</i>

**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.

<i>BNL LSO printed name</i>	<i>Signature</i>	<i>Date</i>
<i>ES&amp;H Coordinator printed name</i>	<i>Signature</i>	<i>Date</i>

APPLICABLE LASER OPERATIONS				
x General Operation	x Alignment	Service/Repair	Specific Operation	x Fiber Optics

## ANALYZE THE LASER SYSTEM HAZARDS

Hazard analysis requires information about the laser system characteristics and the configuration of the beam distribution system.

LASER SYSTEM CHARACTERISTICS					
Laser Type <i>(Argon, CO2, etc)</i>	Wavelengths	ANSI Class	Maximum Power of Energy/Pulse	Pulse Length	Repetition Rate
Semiconductor diode	808 nm	IV	20 Watts CW/peak	Variable, 15-150 ns	CW – 1 MHz

**Cryogen Use**

Describe type, quantity, and use.

none

**Chemicals & Compressed Gasses**

Describe type, quantity, and use.

none

**Electrical Hazards**

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

CW operation – 4 volt dc with 20 Amp maximum current.

Pulsed operation – external trigger at 1 MHz repetition rate with a bunch length (gate width) of 16-microsecond. Trigger runs at one bunch per 5 minutes. Pulse width is set at 150 ns, therefore the duty cycle is 15 %.

**Other Special Equipment**

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

A Labview interfaced PC controller for the current pulser.

**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*).

This diode laser itself does not have an ON/OFF power switch. It is driven by a current pulse source, which is remotely controlled using a Labview interface on a local PC. Because of the potential radiation hazard during beam runs within the vicinity of the equipment, the operators access and control the local PC through PC-Anywhere or a Virtual-Network-Interface from a remote PC. Therefore, a remote PC actually controls the laser. The laser itself is in a sealed package, together with the heat sink it is enclosed in an aluminum housing shown in Figure 1.



Figure 1

Layout of the optical beam transport in the A3 beamline for experiment E951 is shown in Figure 2 and Figure 3. The thin red line is the fiber optics line and the thick solid red line is the optical beam propagating in free space. The laser beam is fiber-coupled into the radiological controlled area where it is diverged at a full opening angle of 23 degree at the fiber output end. A lens then collimates the diverged light to an area of 6 inch in diameter. A mirror steered the optical beam to a diagnostic port near the mercury target area. The fiber coupling terminates at the lens where the light then travels unenclosed with a spatial beam diameter of 6 inch in diameter and exits through the radiation shielded wall where it terminates on a telescope/CCD camera arrangement. The spatial size of the laser beam is converged to 2-3 inch in diameter at the entrance aperture of the telescope. A second telescope/CCD views the window of the target continuously in real time on an off-axis optical beam path – green/yellow line, no laser light propagates in this beam path.



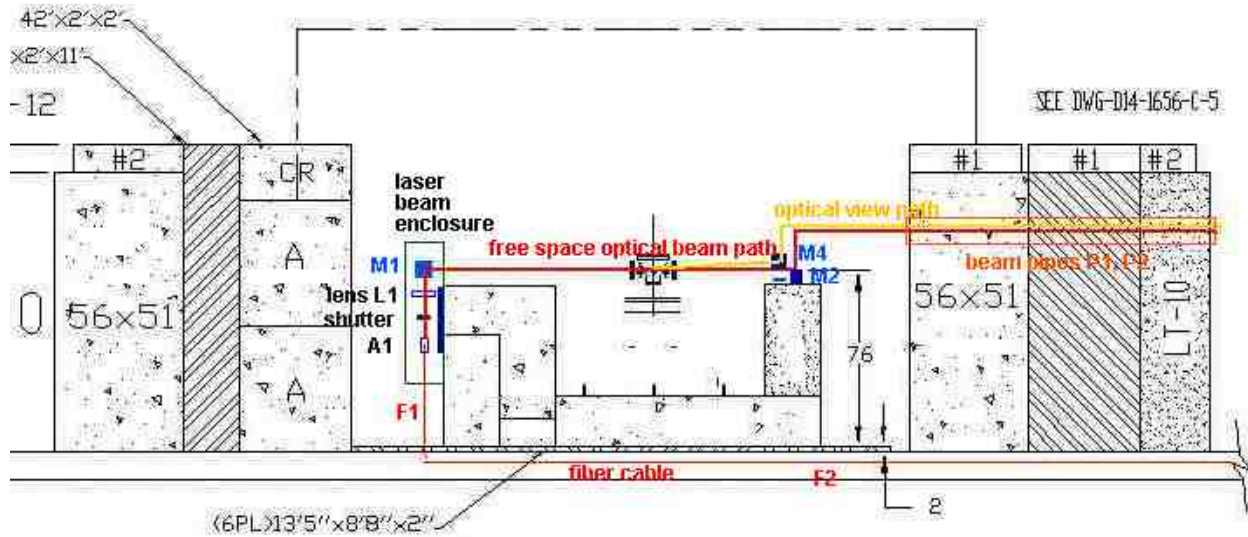


Figure 3

## 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**

<b>ENGINEERING CONTROLS</b>
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- |   |   |                                |
|---|---|--------------------------------|
| <input checked="" type="checkbox"/> Beam Enclosures         | <input checked="" type="checkbox"/> Protective Housing Interlocks | <input type="checkbox"/> Other |
| <input checked="" type="checkbox"/> Beam Stop or Attenuator | <input type="checkbox"/> Key Controls                             |                                |
| <input type="checkbox"/> Activation Warning System          | <input type="checkbox"/> Other Interlocks                         |                                |
| <input type="checkbox"/> Ventilation                        | <input type="checkbox"/> Emission Delay                           |                                |

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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. **Attach a copy of the design review documentation and a written testing protocol. Attach or keep elsewhere any completed interlock testing checklists to document the testing history.**

Engineering Controls Description:

This laser is of Class IV when it operates in CW mode (maximum of 15 Watts), a high current dc power supply is required. When it is operated in the pulsed mode (peak power of 15 Watts in 150 ns pulse width at 1 Hz repetition rate), its classification is lowered to Class IIIb. The laser will not be operated in CW anytime during the experiment and no high current dc power supply is provided. To lower the laser radiation hazard during beam alignment, a low power (1 mWatt) CW red laser diode (Class II laser) is used to align all optics. A metal beam enclosure is placed at the location where the fiber cable couples to the free space optics where laser beam is diverged to the eye level position. A laser interlocked beam shutter is placed at the exit end of the fiber cable. The shutter is interlocked to the entrance gate of the A3 beamline. The location of the interlock switch and the activation button is shown in Figure 4.

To satisfy the laser safety requirement of the AGS operation at the A3 beamline, all optics will be aligned with a Class II laser. For a one-time entrance only (a period of half to one hour), a laser operator will be allowed to enter the A3 cave to perform a final laser beam alignment using the pulsed IR laser under a special Control access mode granted by the AGS safety committee. The laser operator will perform the section 3 of the laser beam alignment inside the cave in the Control access mode with a gate watcher. After final laser beam alignment, upon the exit of the laser operator through the A3 gate, the special Control access mode is terminated. The IR laser can not and will not be operated until A3 cave is ready for proton beam and has went through the Control access procedure. To satisfy such a requirement, the driver of the IR laser and the laser shutter are interlocked to the reset switch of the outer gate. The dry contact (AGS provide) on the reset switch of the outer gate remains open, that is the laser remains disable at all time, until A3 cave is ready for particle beam. When the operation of the gate is in Restricted or Control access modes, the reset contact is open and the laser is disabled.



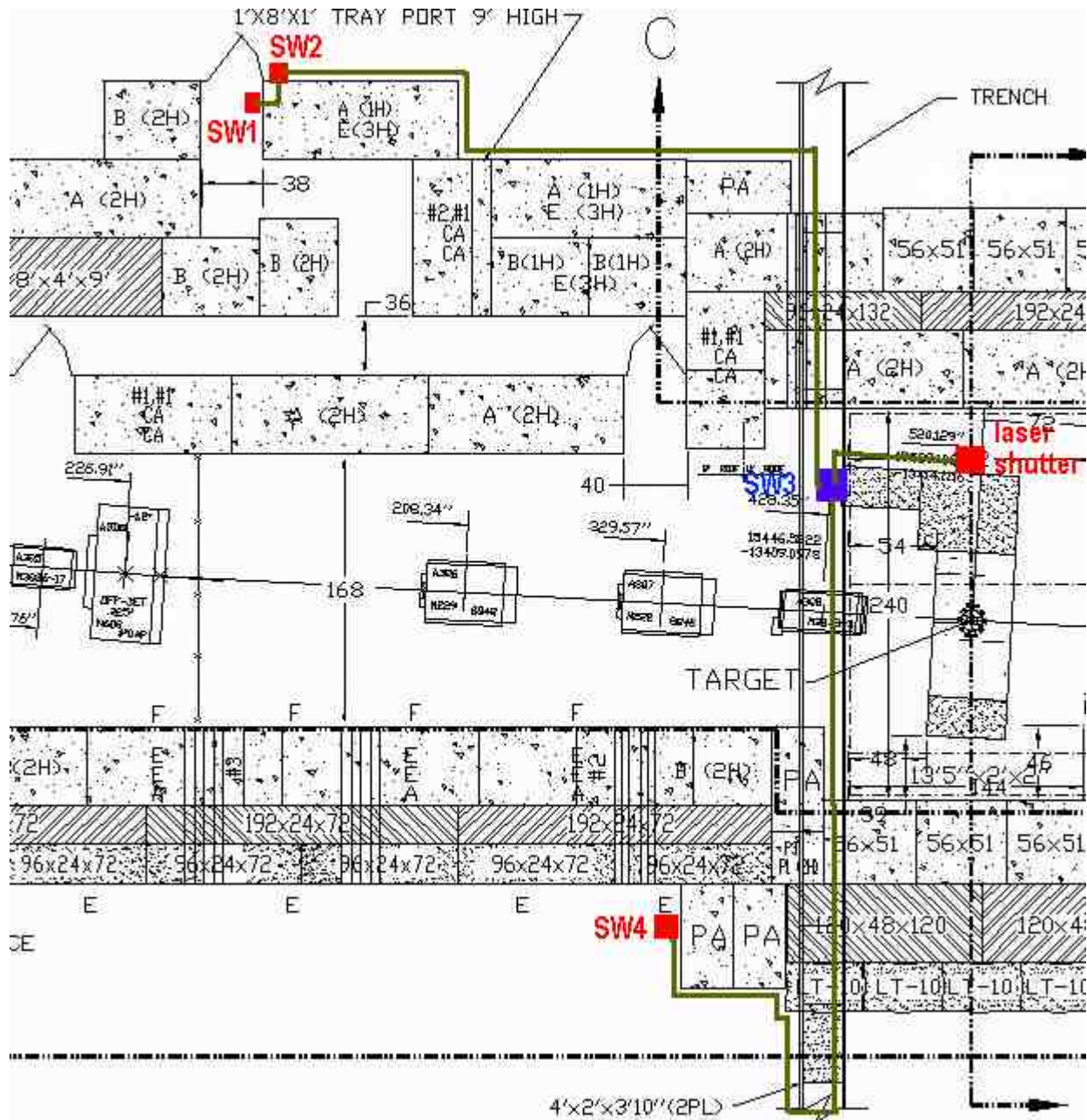


Figure 4

In preparing the laser system for the experiment run, the operation of the laser (and shutter) interlock is described in the following. After CA personnel went through the Control access procedure of the A3 cave and the reset switch of the outer gate has been activated by the operator in the AGS control room,

1. Interlock the laser-controlled area by pushing external interlock button on SW2 once, appropriate LEDs will light up on SW2 and SW4. The laser shutter is now enabled and the IR laser can then be powered.
2. To open the laser shutter, push SW4 once. Appropriate indicator lights will light up on SW2 and SW4. A flashing laser warning sign at the vicinity of SW4 will be turned on when laser light is emitting.
3. Upon completion of the experiment, turn laser off and push SW4 once. Also, the laser power will be disabled when the reset switch is open.

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<b>ADMINISTRATIVE CONTROLS</b>
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x Laser Controlled Area   x Signs            x 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 (SOP) are required for laser system operation, alignment, and maintenance. The SOPs need only contain the steps necessary to perform these tasks and identify when and where posting and personal protective equipment is required. SOPs must be approved by the BNL Laser Safety Officer and should be kept with this program documentation.**

Administrative Controls Description:

Laser warning labels are placed at the entrance gates of the A3 beamline. A flashing laser warning sign is placed at the vicinity of the optical setup around the East side of the A3 cave. The telescopes and the CCD cameras are enclosed in a metal frame. All E951 personnel are briefed about the laser hazard and the safe operation of the laser. At least one qualified laser operator should be at the control console when any one member of the E951 personnel operates the console. Laser beam alignment is done by qualified, trained, laser operators. In E951 experiment only two qualified laser operators, Thomas Tsang and Harold Kirk, are allowed to align and manipulate the optics.

There are 4 sections of optical alignment procedures.

The first procedure is proceeded from the beam pipe P1, where the telescope is located, to the fiber-optic assemble A1.

1. Shine a low power (1 mW ) red laser diode at the center of the beam pipe, P1, to the final turning mirror, M3.
2. Align red laser beam from M3 to M2.
3. Align red laser beam from M2 to M1.
4. Align red laser beam from M1 to the center of L1 and onto the center of the fiber-optic cable launch assembly, A1.
5. Plug the exit end of the beam pipe, P1, with metal disk.

The second procedure is proceeded from the fiber-optic assemble A1 back to the beam pipe P1.

6. Connect a fiber coupled 1 mW red laser diode to the entrance end of the jumper fiber cable F1.
7. Adjust the focusing of the lens L1 until an optimum focusing condition is obtained on P1.
8. Make any necessary mirror adjustment to center the beam on P1.

The third procedure is done using the IR laser operated in pulse mode. A laser operator is allowed to enter the cave in a special Control access mode with gate watcher

9. Interlock and secure the laser-controlled area. Wear laser protective goggles.
10. Disconnect the fiber-coupled red laser diode from fiber cable F1.
11. Connect fiber cable F2 to F1.
12. Operate the IR laser in pulse mode at -10 volt (5 Watt peak optical power output).
13. Make all necessary minor optical adjustment to send IR beam from A1 to the center of the beam pipe P1.
14. Confirm the beam alignment by viewing the IR beam using an IR fluorescence card or an IR handheld viewer.



Laser alignment is done.

The last procedure is to align a second telescope for off-axis viewing the target window.

15. Shine a low power (1 mW ) red laser diode at the center of the beam pipe, P2, to the turning mirror, M5.

16. Align red laser beam from M5 to M4 and onto the center of the target.

All optical alignment is done.

Because the laser diode is packed in a completely sealed package, no laser maintenance or service is required. However, the optical alignment may need to be checked periodically by following the second alignment procedure with a low power red diode laser.

The optical setup of the E951 experiment is shown in Figure 5.

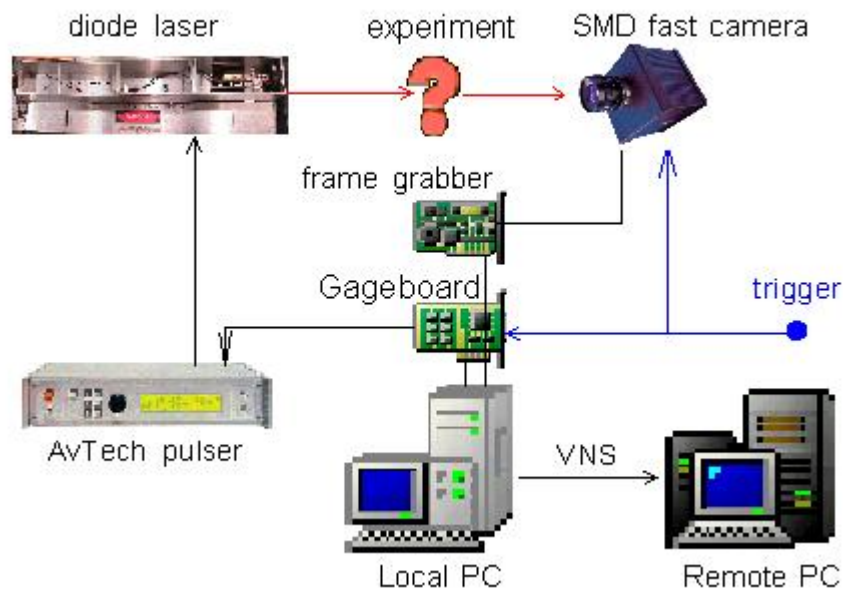


Figure 5

A trigger signal is derived from the fiber-optics trigger light pulse. It is then converted to an electronic TTL signal – G10 trigger. The G10 signal triggers the fast camera and a Gage CompuGen 1100 PC board pulse generator at the proton beam cycle - about 1 Hz. The Gage board generates a 16-pulse train per proton bunch. Each pulse has 0.5 microsecond duration in one microsecond period. The electrical pulse train is then used to trigger the Avtech current pulser. The operating procedures are (sample front panel is shown below):

1. From the Start menu, open E951-optics menu, select Start-Electronic-trigger.
2. Click Waveform Editor.
3. Open signal files in D:\E951-optics directory: GaGe-16-pulse-1-us.sig for 16-pulse 1 microsecond period, GaGe-16-pulse-10-us.sig for 16-pulse 10 microsecond period, etc..
4. Expand and view the signal waveform.
5. Select Setting – Trigger Setting – External.
6. Select Setting – Loop Setting – Multishot – 4.
7. Click GEN button on the Waveform Editor panel to generate and output the waveform.

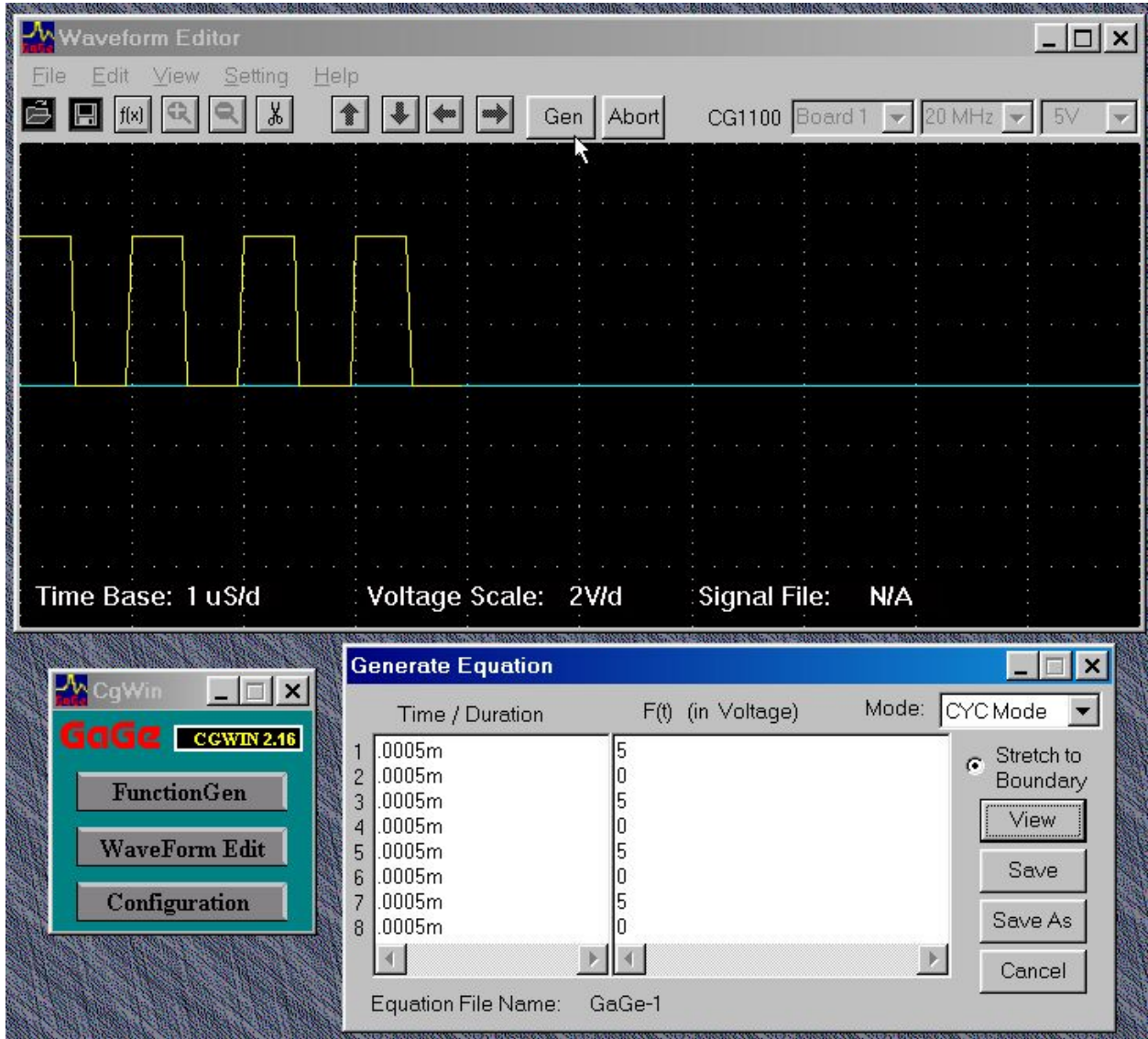


Figure 6

The laser diode is driven by an Avtech current pulser model # AVOZ-A1A-B-N. This pulser is controlled by a LabView interface via an IEEE bus and is triggered by the Gage board. The operating procedures of the laser driver are (sample front panel is shown below):

1. From the Start menu, open E951-optics menu, select Start-laser-trigger. An Avtech-pulse.vi will initiate.
2. Set (or confirm) IEEE address to 8.
3. Set output voltage level to -20 volt.
4. Set (or confirm) trigger to External.
5. Set (or confirm) pulse width to 150 ns.
6. Initiate the pulser by running the vi once.
7. When proton beam is available, activate the laser interlock. Click the Output Status button to LASER ON and run the vi.

8. Laser is now ON and is firing 16 pulses, 150 ns duration per pulse, at the repetition rate of the proton beam – once every 5 minute.

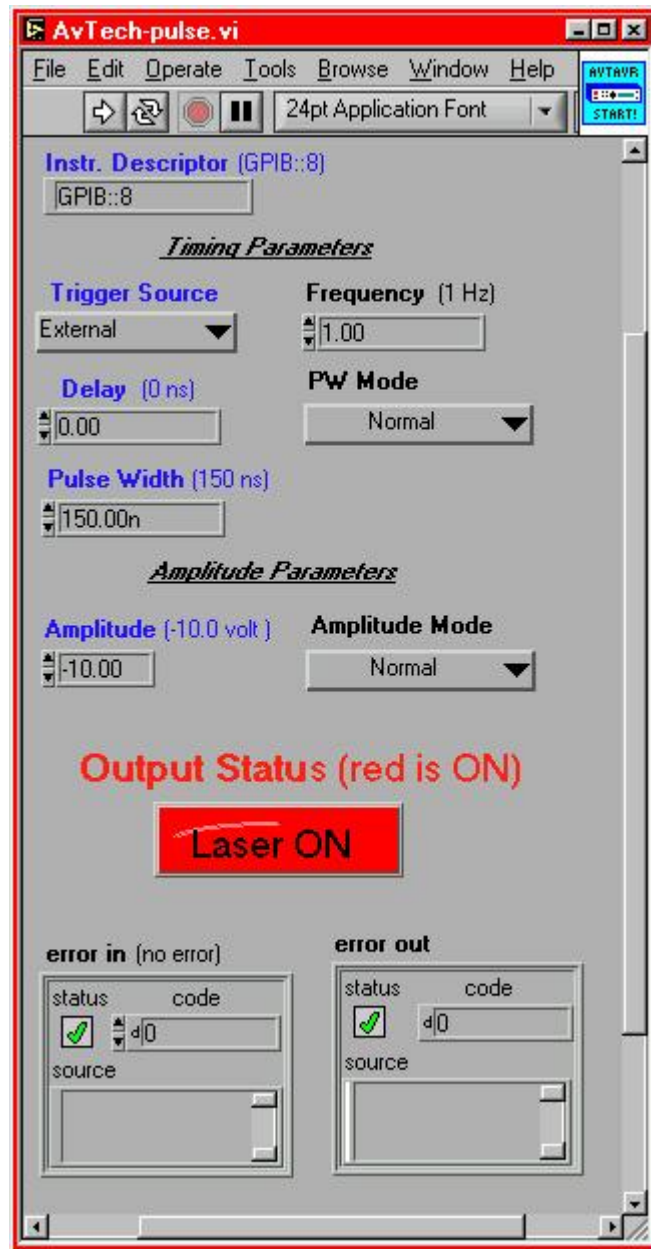


Figure 7

A fast CCD camera, SMD-64K1M that is also triggered by a trigger pulse arriving once every 5 minutes captures the image of the target. The camera has a dynamic range of 11-12 bit (4096) of resolution. Its operating procedures are (sample front panel is shown below):

1. From the Start menu, open E951-optics menu, select Start-fast-camera.
2. Click Acquire (the icon with a camera) once. System will then initiated.
3. Set Ext. Trig. to SYNC, Integ. Time to 0.001, gain to 1.0, and pause time to 0.
4. Double click on the Acquire button. Acquire Parameter menu will pop-up.
5. Check the Non-stop Acquire box. If single image viewing is preferred check the Raw Multi-Exposure box (the single image will be displayed in a nice rectangular window rather than in a tilted window).
6. Go to the main display menu. Select Tool-Options-Nonstop acquire display-image statistics submenu. Uncheck the Show Histogram and Show General Statistics boxes.

7. Click OK. 16-image or a single image will be displayed in real time.
8. To save image: click File – Save As – check 12-bit option – type in the file name.

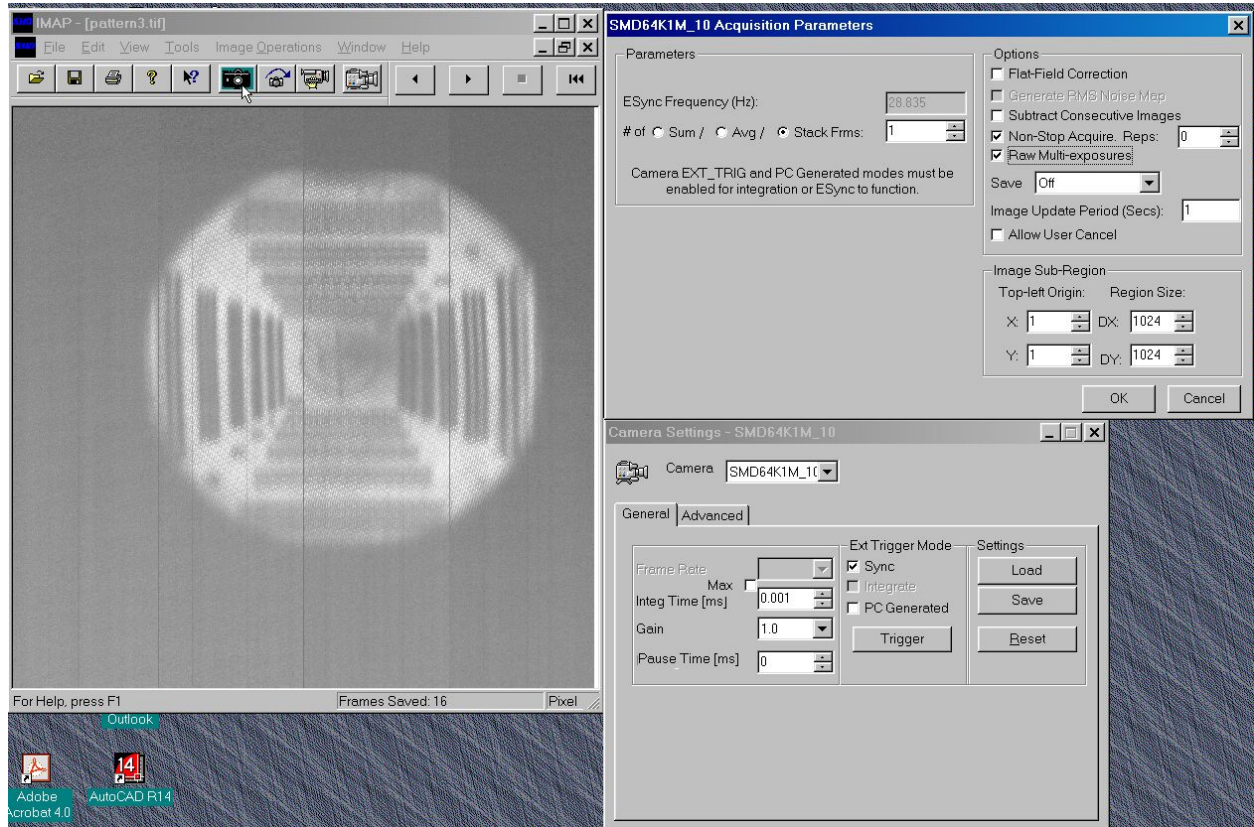


Figure 8

The system is now ready for the experiment. Display all front panels on the monitors and activate the VNS (virtual-Network-Computing) interface. A sample of the control/monitor panels is shown here.



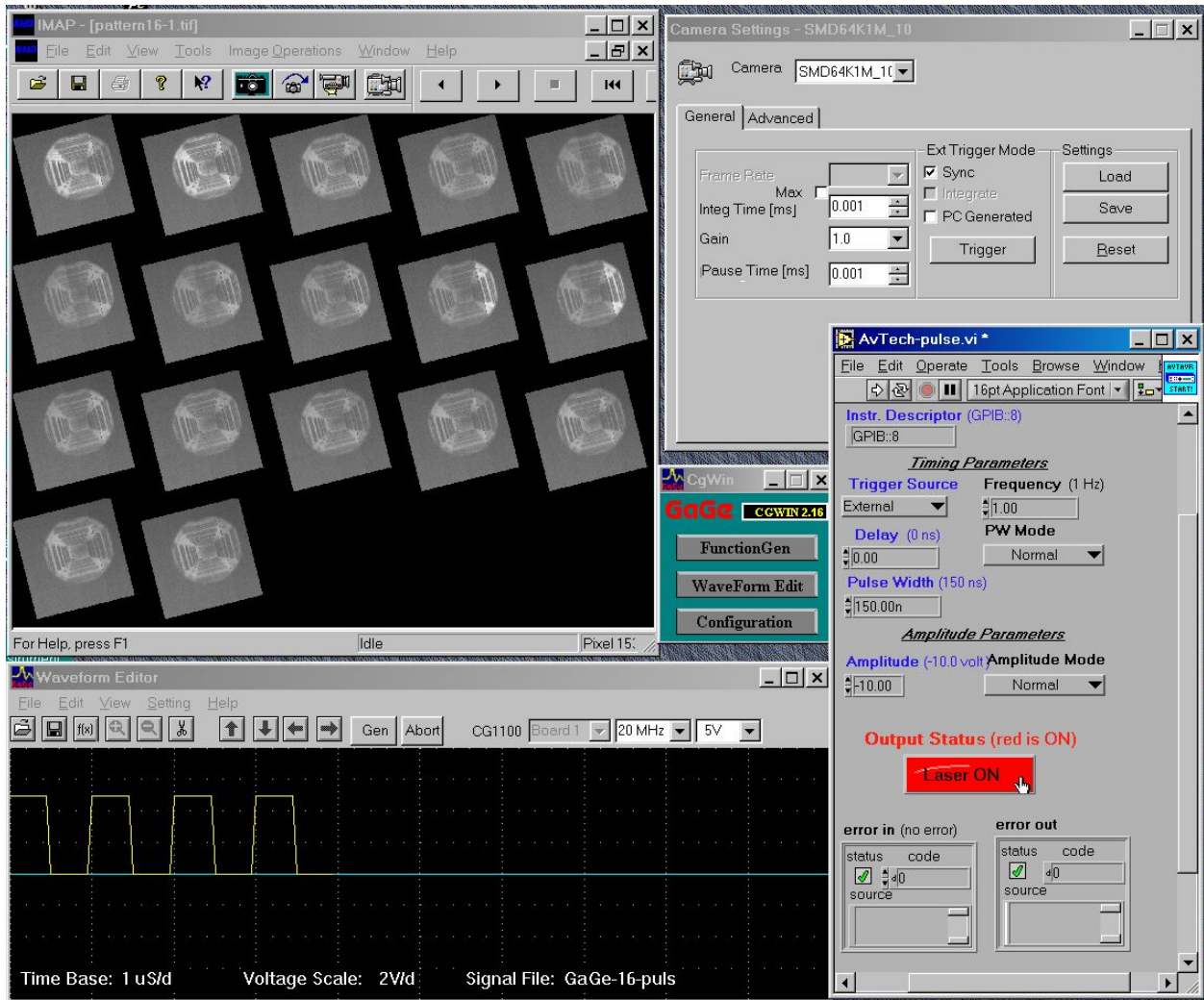


Figure 9

Detail on the characteristics of the laser is given in the following. Although this laser unit has 2 identical laser diodes each capable of emitting 7 Watt of power, only one laser diode is in used (bottom laser diode). The dc current-voltage-light and the ac voltage-light characteristics are shown in Figure 10(a). At the maximum pulse voltage of  $-20$  volts, 12 Watts of peak power is emitted. However, the light intensity temporal profile varies with drive voltages, see Figure 10(b), and is of triangular shape.



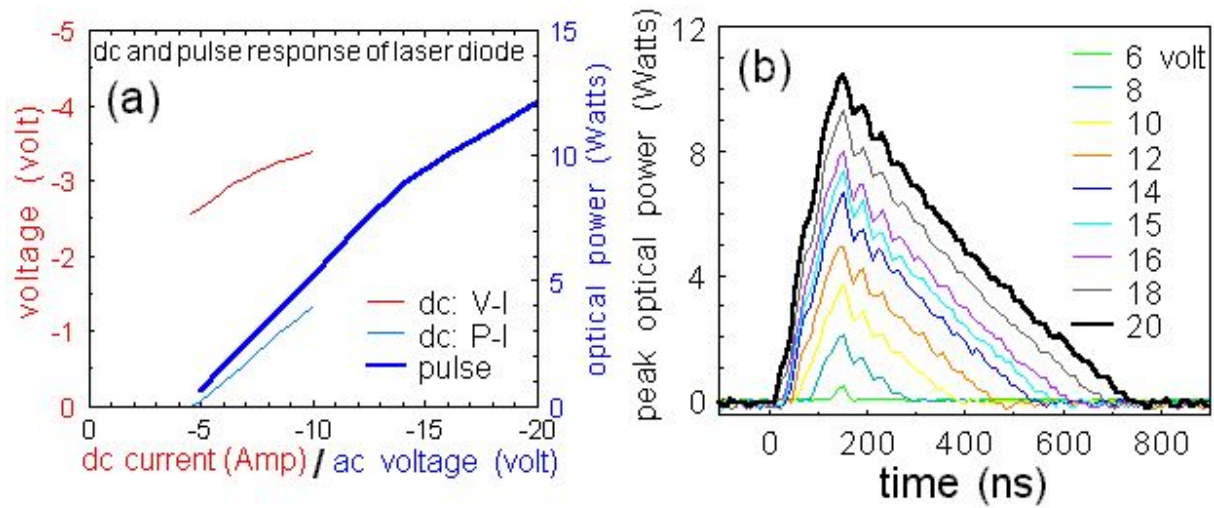


Figure 10

When a 16-pulse train triggers the laser, the intensity of the 16 laser pulses varies, see Figure 11. The light intensity drops by a factor of 2 from the first to the third pulse. This light intensity drooping is also noticeable on the captured image, see Figure 9. However, the temporal shape of all 16 pulse is maintained - triangular. The phenomenon of light intensity drooping and triangular shaped temporal profile is a result of the limited electrical bandwidth of the laser and the limited pulse duration of the voltage driver (maximum of 150 ns).

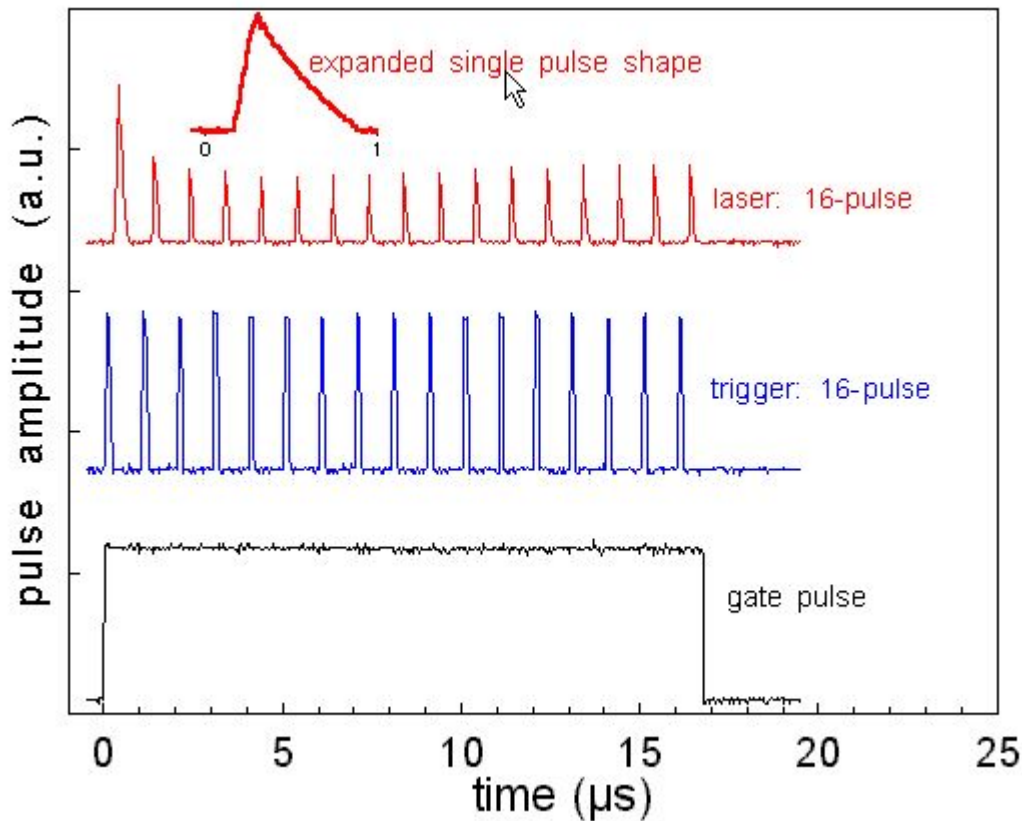


Figure 11

During the experiment if one needs to reduce the number of photons reaching the camera by reducing the pulse width or the pulse voltage of the laser driver, one should aware that either techniques produce nonlinear laser output intensity, as shown in Figure 12.

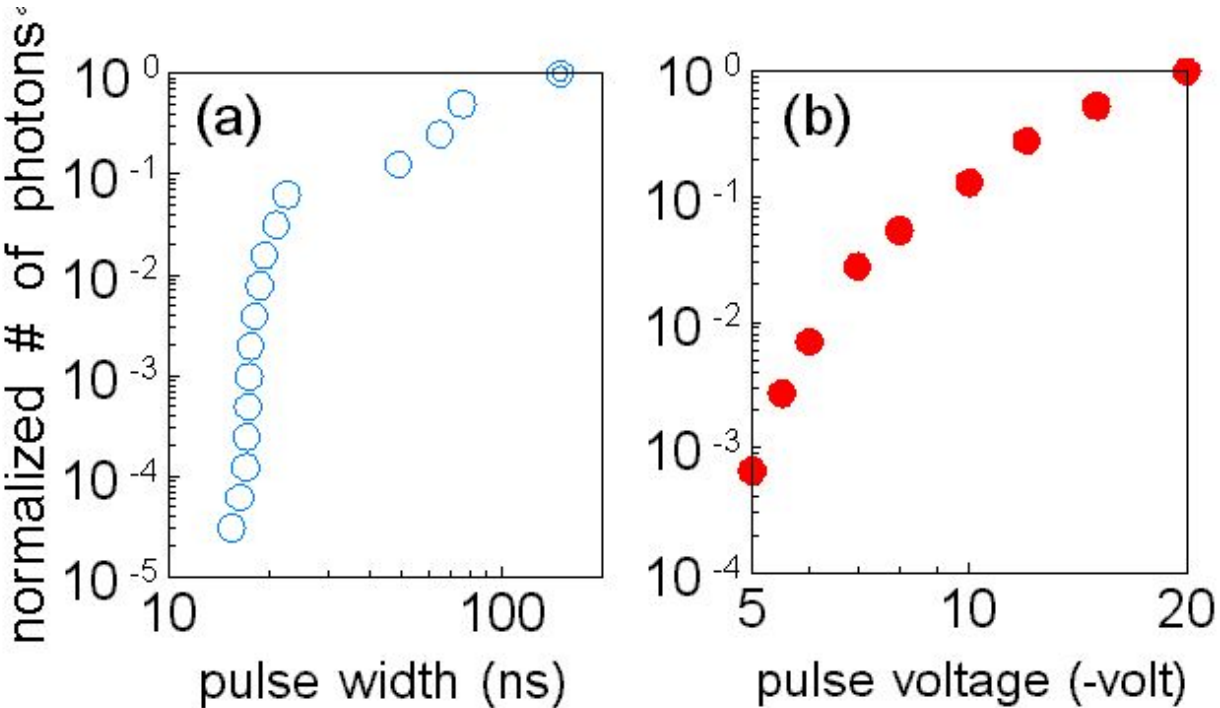


Figure 12

**CONFIGURATION CONTROL**

Prepare and attach a checklist to be used for configuration control of any protective housings, beam stops, beam enclosures, and any critical optics (*mirrors or lenses that could misdirect the beam and result in personnel hazard*). Include entries 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.

**PERSONAL PROTECTIVE EQUIPMENT**

x Eye Wear                       Skin Protection

**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.

**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.

<b>EYE WEAR SPECIFICATIONS</b>			
Laser System Eyewear Identification	Wavelengths	Intra-beam Optical Density	Diffuse Optical Density
Edmund K53-291	808 nm	3-4	
Edmund K38-218	635 nm	>5	

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.

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.

## TRAINING

<b>LASER SAFETY TRAINING</b>
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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 BNL World Wide Web based training course ([BNL course #HP-IND-011](#)).

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
  - Review of this program documentation
  - Review of SOPs

All laser safety training must be repeated every two years.

<b>MEDICAL SURVEILLANCE</b>
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Operators of ANSI Class 3b and 4 laser systems must complete a baseline medical eye examination prior to laser system operation. Any qualified ophthalmologist may complete this exam. BNL has arranged for this service from the following local physicians:

Dr. Charles Rothberg  
331 East Main St.  
Patchogue, NY 11772

The Ophthalmic Center  
Dr. Basilice  
3400 Nesconset Highway  
East Setauket, NY 11733

East End Eye Associates  
Dr. Sherin  
669 Whiskey Road  
Ridge, NY 11961

631 758-5300  
\$65 per exam

631 751-2020  
\$60 per exam

631 369-0777  
\$125 per exam

Personnel using physicians other than those listed must have their examination records forwarded to the BNL Occupational Medicine Clinic.

### FEEDBACK AND IMPROVEMENT

Comments and suggestions for improvement should be directed to BNL-Laser Safety Officer, Chris Weilandics (X2593; weil@bnl.gov).

### LASER USER QUALIFICATION

Personnel qualified to work with this laser system are listed below. These Qualified Laser Operators must understand the information and conform to the requirements contained in this document. For training and medical surveillance, enter the date of completion.

**Qualified Laser Operators:**

Basic Laser Training	Job-Specific Training	Medical Surveillance	Printed Name	Signature	Owner/Oper. Initial/date
10/25/00	X	2001	Thomas Tsang		
4/26/99	X	1999	Harold Kirk		

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#### Appendix A: Laser interlock test procedure

Two individuals, one stands outside the A3 gate near the SW2 switch and another at the SW4 switch. Two way radios. One for each individual. In each step, one person performs task. The other is making observations and reporting back.

##### Testing laser interlock:

When the A3 gate is not in reset mode, the ac line power of the laser driver is disabled. When the AGS operator reset the A3 gate, the ac line power of the laser can be enabled.

1. When the A3 gate is opened by one person the other person should observe the ac power to the laser driver (at SW4 location) drops.
2. When the A3 gate is reset by an AGS authorized personnel, the other person should observe the ac power to the laser drive (at SW4 location) enabled.

#### Appendix B: Shutter testing procedure. (by Marc Montemagno) *Not required in this beam run.*

Note: In each step, the first person mentioned is the one performing a task. The other two people are making observations and reporting back.

Note: One person should be in charge of running the test, while the other two report back. This is to ensure that no steps are missed.

1. Refer to Figure 6.
2. One person should be placed just within the entrance by SW1, the second just outside the entrance by SW2, the third by the main control panel by SW4.
3. Close door.
4. Check all boxes, SW1, SW2, SW3 and SW4, ensure that all LEDs are off.
5. Person inside – check that the shutter is in the closed position.
6. Person inside – attempt to open the shutter by pressing the shutter open button on SW3. Shutter should *not* open.
7. Person main unit – attempt to open shutter by pressing the shutter open button on SW4. Shutter should *not* open.
8. Person inside – press internal interlock button on SW1. Enable and interlock LEDs should light.  
 Person outside – should only see the interlock LED on SW2. Yellow flashing.  
 Person main unit – should see all LEDs off.
9. Person inside – go to SW3 and press shutter open button. Blue LED should light and shutter should open.  
 Person outside – no change.  
 Person main unit – Blue shutter open LED should light.



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10. Person main – press shutter close button. Blue LED should stay on.  
Person outside – no change  
Person inside – shutter should stay open. Blue LED should stay on.
11. Person inside – close the shutter by pushing the close button on SW3. Blue LED should go out and the shutter should close.  
Person main – Blue LED should go out.  
Person outside – no change.
12. Person main – press the shutter open button on SW4. Should have no effect.  
Person inside – observe that the shutter did *not* open.  
Person outside – no change.
13. Person inside – press the shutter open button on SW3. Blue LED should light.  
Person main – Blue LED should light.  
Person outside – no change.
14. Person outside – open door. LEDs on both SW1 and SW2 should go out.  
Person inside – Shutter should close and both LEDs on SW3 should go out.  
Person main – Both LEDs should be off.
15. Person outside – close door. All LEDs should still be out at SW1 and SW2.  
Person inside – attempt to open the shutter by pressing the open button. Shutter should remain closed.  
Both LEDs should still be out on SW3.  
Person main – both LEDs should still be out on SW4.
16. Person main – press the shutter open button on SW4. LEDs should remain off.  
Person inside – observe that the shutter did *not* open. LEDs should remain off.  
Person outside – ensure that all LEDs remained off on SW1 and SW2.
17. Person outside – press the outside interlock button on SW2. Both LEDs should light on SW2.  
Interlock LED, flashing yellow, should light on SW1.  
Person main – the enable LED should be on, flashing yellow on SW4.  
Person inside – Both LEDs should be out on SW3.
18. Person main – press the shutter open button on SW4. Blue LED should light.  
Person inside – the shutter should open and the blue LED should light on SW3.  
Person outside – no change.
19. Person main – press the shutter close button on SW4. The blue LED should turn off.  
Person inside – the shutter should close and the blue LED should turn off.  
Person outside – no change.
20. Person inside – press the shutter open button on SW3. The shutter should *not* open.  
Both LEDs should still be out.  
Person main – the blue LED should remain off. The enable LED should still blink.  
Person outside – no change.
21. Person main – press the shutter open button. The blue LED should light on SW4.  
Person inside – the shutter should open and the blue LED should light on SW3.  
Person outside – no change.
22. Person outside – open the door. All LEDs should go out on both SW1 and SW2.  
Person inside – the shutter should close and all LEDs should be off.  
Person main – all LEDs should go out on SW4.

