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

This document defines the safety management program for the laser system(s) 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*. Modify the template for this document to fit your particular circumstance.

System description: Single-Crystal Raman Spectroscopy Apparatus utilizing 3 Class 3B diode lasers
Location: Associated with beamline X26-C at the NSLS

LINE MANAGEMENT RESPONSIBILITIES

The Owner/Operator(s) for this laser is/are 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:	Allen M. Orville, Ph.D.	*Signature: On file*	*Date:*
	Feifei Li, Ph.D.	*Signature: On file*	*Date:*
	Alexei Soares, Ph.D.	*Signature: On file*	*Date:*
	Grace Shea-McCarthy	*Signature: On file*	*Date:*
		Signature: On file	*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. Additional signatures, *e.g.*, the ALSO are to be added to this signature block when necessary.

BNL LSO printed name	*Signature On file*	*Date*
Department ES&H Coordinator printed name	*Signature On file*	*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.

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)
Diode-pumped solid-state (DPSS) laser	532 nm (green region)	3b	311 mW	NA (CW laser)	NA	Coupled into 100 micron optical fiber
External cavity diode laser	785 nm (red region)	3b	323 mW	NA (CW laser)	NA	Coupled into 100 micron optical fiber
Continuous Wave (CW) Diode-Pumped Solid State Laser (DPSS)	473 nm (blue region)	3b	50 mW	NA (CW laser)	NA	Coupled into 100 micron optical fiber

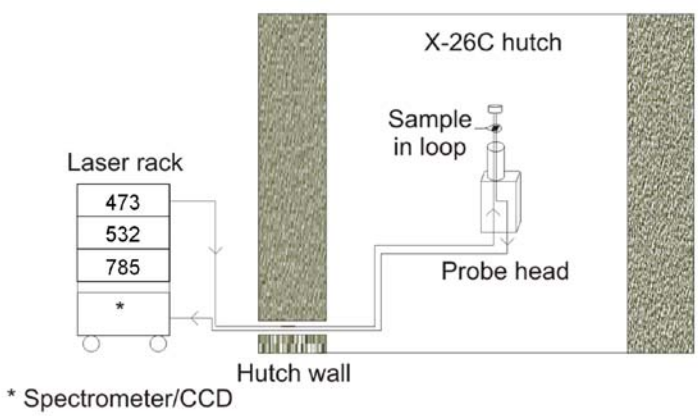
Applicable Laser Operations:
*Describe the scope of the work to be done, and how the laser system is used. Provide information regarding unusual circumstances necessary for evaluation of hazards by the LSO not provided elsewhere in this document (*e.g.*: laser beams entering other equipment such as vacuum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

These lasers are to be used as the excitation source for the generation of Raman spectra from protein crystals. The laser output is fed directly into fiber optic cables which direct the beam to the crystal, located inside the X-26C hutch. Back-scattered light from the sample is collected into a second fiber optic and carried to the spectrometer and detector.

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.

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).

The lasers are located in an interlocked, fully enclosed 12U box with wheels equipped with a 19'' rack together with the spectrometer, detector and thermoelectric cooler (Appendix - Photo 1). Photo 2 shows a close-up of the laser control panels at the front of the rack. Each laser is equipped with an interlocked "enable" signal, which is "disabled" when the rear door of the laser electronic rack is opened. The rear panels with the laser aperture for each of the lasers are shown in Photo 3. The upper laser is shown with the fiber optic attached. The fiber optic carries the laser beam out of the rack, through an access port into the hutch (Photo 4) and attaches to the bottom of the Raman probe head (Photo 5). The laser is focused onto the protein crystal attached to the goniometer (Photo 6). Back-scattered light (180°) is collected through the same objective, passes through the probe head where the laser line is removed and the remaining scattered light is collected into a fiber optic (Photo 5 – Raman Aperture). The fiber optic passes through the same hutch access port shown previously and enters the spectrometer (Photo7) located in the laser rack.



There is a short section (~10 - 25 mm, depending upon the objective in use) of open beam path at the sample area in the X-26C hutch. "Laser in Use" postings will be displayed on the hutch door, and laser specific training will be documented for all laser users. Laser trained users will not require eye exams or Laser operator attendance when operating < 5 mW. This power range is considered low risk due to the short exposed laser path. Laser beam alignment to the sample coincident with the crystal rotation and x-ray beam path can be done remotely. We have installed network computers, motorized XYZ translation slides, and a Raman microprobe which includes a color video camera that "looks" through the laser probe objective.

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**

There is no cryogen use associated with the laser. A cryostream of liquid nitrogen is utilized within the X-26C hutch for collection of x-ray diffraction data. Refer to the SOP for the X-26C beamline.

☐ **Chemicals & Compressed Gases**

None

☐ **Electrical Hazards**

Describe circumstances that could lead to exposure to electrical hazards.

The power supply for each laser is located within the interlock protected laser rack on the same shelf as the laser. There are no serviceable components within the power supply

☐ **Other Special Equipment**

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

Spectrometer, CCD detector, and thermoelectric cooler for the CCD are all located within the laser rack.

DESCRIBE CONTROLS

Terminology:

"Authorized User", (Laser Operator) refers to those who have completed the online laser training course, had a baseline eye exam and have been trained on this system. They are permitted to use the key controls and operate the laser, switch Raman probe heads, and be in the hutch with appropriate eye wear when the laser is on. They may align the laser beam with the sample using the remote controls outside of the hutch.

"Laser Users" are those who have completed the online laser safety course and have been trained on this particular system. They are not permitted inside the hutch, without a "Laser Operator", when the laser power is above 5 mW. They may align the laser beam with the sample using the remote controls outside of the hutch. They may shut off the laser. Laser trained users will not require "Laser Operator" attendance or eye exams when operating < 5 mW. This power range is considered low risk due to the short exposed laser path.

<u>Recognition, evaluation, and control of laser hazards are governed by the following documents:</u>

American National Standards Institute (ANSI) Standard for Safe Use of Lasers (ANSI Z136.1-2007)

BNL SBMS Sections:

Laser Safety Subject Area
Interlock Safety Subject Area

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: The laser is fully enclosed, exits via a coupler into a 100 micron fiber optic. The beam is only exposed at the sample and for a distance of less than 2.5 cm.

Beam stop: During data collection, the objective installed above the sample serves as a beam stop.

Activation warning system: The 532 laser power supply LED screen displays 'Danger! Laser emission' when the laser is on. The 473nm and the 785 nm lasers display a "laser enable/on" LED.

Protective housing interlocks: The laser rack is equipped with interlocks.

Key controls: Master key to the power supply and the individual laser keys will be under the control of the laser owner. Only Authorized Users will be allowed to use the keys and operate the laser system when operating at power > 5mW. Laser trained users may have use of keys when operating < 5 mW.

Emission delay: The 785 nm laser has a 7 second delay before emission. (The 532 nm and the 473 nm laser do not have a delay.)

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.

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.

Laser controlled area: Inside either the interlock protected X-26C beamline hutch, or inside the adjacent optics lab at the beamline. Additional SOP requirements for the optics lab, (inclusive of door interlocks), will be considered prior to using lasers in the offline enclosure.

Signs: Danger, Class 3b laser, Power <500 mW posted on door to the X-26C hutch and the laser rack.

Labels: Warning labels have been affixed by the laser manufacturer and will not be removed.

<u>Operation:</u>

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

Only Authorized Users are permitted to use any of the laser systems when operating > 5 mW.
The door to the X-26C hutch must be closed and the "Laser in Use" posting in place.

473 nm laser:

- Insert the 473 nm laser key and turn to the "ON" position.
- To activate the Laser press down on the "REARM" toggle switch. The white LED will illuminate, indicate laser emission.

532 nm laser:

- Laser can be operated between 10 and 35°C. Thermal shutdown will occur at ~45°C.
- Switch the 12 VDC source on so that the mpc6000 power LED illuminates. At this stage the thermal control circuitry is activated but no laser emission should occur.
- It is necessary to close the *Interlock* connection before the laser can be operated. This is done by turning the supplied *Enable* key to the 'on' position. The laser is then turned on by briefly pressing the Enable button.
- To adjust the current, select the parameter *current* displayed on the LCD screen by pressing the menu down button (↵). The text will turn from green to blue. Use the rotary encoder to select *current* and press the menu down button again. The text will now be red. Use the rotary encoder

to change the value for the current (pressing the rotary encoder while turning allows the value to change more quickly). Once at the desired value, press the menu up button twice (↩).
- The laser is switched off by turning the keyswitch to the ‘off’ position or by breaking the interlock of the laser rack back panel or at the entrance to the hutch/laser enclosure.

785 nm laser:
- Operate the laser only between 15 and 35°C. Thermal shutdown will occur at ~40°C.
- Use the current adjust knob to change the laser current or power to the minimum setting to avoid facet damage of the laser diode.
- Turn on the key switch. There will be a 7 second delay before the laser comes on. Let warm up for 10 minutes.
- Adjust the current adjust to the desired level.
- To shut the laser off, always reduce the current to the minimal level and switch off the laser. The laser will also be shut off if the interlock at the hutch/laser enclosure door or the back panel of the laser rack is broken.

<u>Maintenance/Service:</u>

Describe additional controls required to maintain laser operation. May or may not require beam access. Follow manufacturer instructions where appropriate.

473 nm laser:

This laser is designed to be maintenance and adjustment free. The laser will not be opened or adjusted by anyone other than Process Instruments certified technicians

532 nm laser:

If the laser is operated in a smoky or dirty environment, occasional cleaning of the laser window may be required. This is only to be done by Macromolecular Crystallography Research Resource (PXRR) personnel who are Authorized Users. To do this:
- Turn off the laser
- Using an optical cloth dampened with research grade methanol, gently wipe the laser window.

Cautions:
- Never touch the connector on the back of the laser head with anything other than the power lead supplied
- Do not open up the laser head or the Power supply unit; this will invalidate the warranty.
- Do not subject laser to mechanical shock. If severe, this can cause misalignment of the laser cavity.
- Do not touch the output window of the laser. This will damage the optical coatings.
- Do not use or store this laser system in very humid or damp environments.

785 nm laser:

This laser is designed to be maintenance and adjustment free. The laser will not be opened or adjusted by anyone other than Process Instruments certified technicians.

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.

<u>Alignment:</u>

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.

The diode lasers cannot be aligned except by the manufacturer. The Raman probe heads contain optical components which are factory set and typically do not require adjustment following installation. Laser beam alignment with the sample, such that it is coincident with the crystal rotation and x-ray beam path, will be done remotely from outside the hutch. We have installed network computers and motorized XYZ translation slides to facilitate this procedure. In addition, the Raman microprobe includes a color video camera that "looks" through the objective, allowing visualization of the crystal when the laser is off.

Alignment SOP:

If laser alignment to the crystal needs to be done from inside the hutch, the following precautions will be observed:

Alignment of the laser will be performed at lowest power possible (<5 mW). The hutch will be closed during alignment to prevent exposure. Appropriate eyewear will be worn as detailed in the Eyewear section below.

1. The laser alignment may be performed using the Raman signal of the sample as recorded by the computer outside the hutch, eliminating the need of viewing the beam.
2. 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.
3. All equipment and materials needed are present prior to beginning the alignment
4. All unnecessary equipment, tools, combustible material have been removed to minimize the possibility of stray reflections and non-beam accidents.
5. There shall be no intentional intrabeam viewing with the eye!!
6. Maintain good housekeeping practices on laser tables; keep the area where you will be working clear of excess objects that might scatter a beam unpredictably, and keep combustible materials away from class 4 hazards or focused 3B lasers.
7. Consider the use of low power class 1-3A/3R coaxial CW alignment lasers when convenient.
8. During alignment procedures, only persons immediately involved in the procedure are to be in the LCA.
9. When it is possible that hazardous beams are not completely contained on the laser tables, the room must be posted with a temporary alignment warning sign on the door warning those that may enter not to until the procedures are completed and the sign removed.
10. During all times when the possibility for inadvertent exposure to laser light exists, appropriate laser safety eyewear must be worn. The appropriate ratings are listed in the PPE section, and discussed further below.
11. Definite termination of the beam path must be in place before the beam is allowed to propagate. Use moveable beam stops to ensure that uncontrolled propagation does not occur.
12. Alignment procedures are always to be performed with the minimum practical laser power levels and repetition rates.

13. Pre-position optical components during gross alignment as best as possible and secure them before allowing beams to propagate.

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

<u>Laser system configuration changes:</u>

*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).*

This laser system has the option of using one of three wavelengths: 473nm, 532 and 785 nm. Switching between wavelengths require swapping one microprobe for the other inside the hutch on the XYZ translation stage. These changes will only be done by Authorized Users. Current status will be noted on white boards at the hutch and in logs.

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.

Skin protection is not required.

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.

We will supply laser safety goggles for the laser wavelengths in use at the beamline.

LASER SYSTEM CHARACTERISTICS							
Laser Type *(Argon, CO_2, etc.)*	**Wavelength(s) (nm)**	**ANSI Class**	**Maximum Power or Energy/Pulse (J or W)**	**Nominal Power At Sample**	**Pulse Length (s)**	**Repe-tition Rate (Hz)**	**Beam Dia-meter (mm)**
Diode	**532 nm**	**3b**	**311 mW**	**100% = 25mW** **50% = 6 mW** **45% = 4 mW**	**NA**	**NA**	
Diode	**785 nm Laser Operator Required**	**3b**	**323 mW**	**100%=26.1mW** **50% = 23.5mW** **10%=19.0 mW** **2% = 18 mW**	**NA**	**NA**	
Diode	**473 nm**	**3b**	**50 mW**	**Fixed 4.4 mW**	**NA**	**NA**	

EYEWEAR REQUIREMENTS					
Laser System Hazard	Wavelength (nm)	Calculated Intra-beam Optical Density	Diffuse Optical Density*	NHZ** (meters)	Appropriate Eye Wear***
Direct, reflected, diffuse	532 nm	2.8 (10 sec.)	NA	0.08	Laservision LLC cat.# F12-00170.000
Direct, reflected, diffuse	785 nm	2.5 (o.25 sec.)	NA	0.1	Laservision LLC cat.# F12-00170.000
Direct, reflected, diffuse	473 nm	2.5 (o.25 sec.)	NA	0.1	Laservision LLC cat.# F12-00170.000

EYEWEAR SPECIFICATIONS		
Laser System Eyewear Identification***	Wavelengths	Optical Density
Laservision LLC cat.# F12-00170.000	190-535 nm 633-650 nm 650-690 nm 690-1300 nm 1064 nm	7+ 2+ 3+ 6+ 8+

* 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 Users must complete the online laser safety course to assure that they can identify and control the risks presented by the laser systems they use. Owners/Operators and Authorized Users must receive a baseline medical surveillance eye examination, documented in the Occupational Medicine Clinic before using lasers. Owners/Operators and Authorized Users must complete the awareness level BNL online training course (TQ-LASER) every two years.

All users 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.

Each fully-certified person must complete these minimum training requirements. A log of the certified personnel will be maintained by the beamline scientists responsible for the apparatus.

APPENDIX

Photo 1: Front view of rack containing the lasers, spectrometer and thermal cooling unit.

Photo 2: Close-up of the control panel and external interlock port for each of the lasers.

Photo 3: Rear view of lasers inside the rack.

Photo 4: Fiber optic access point into hutch

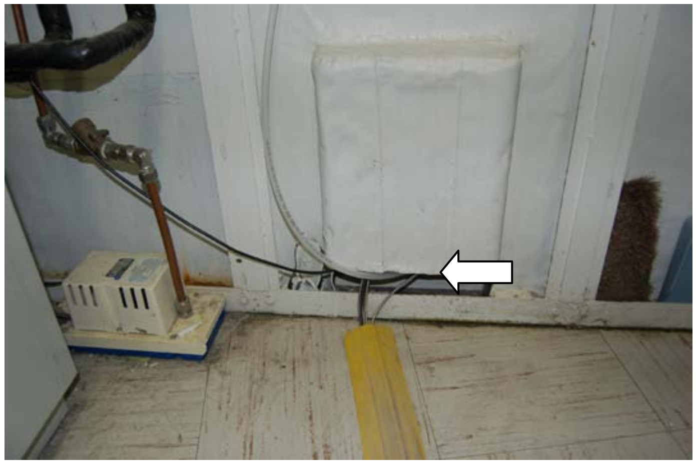
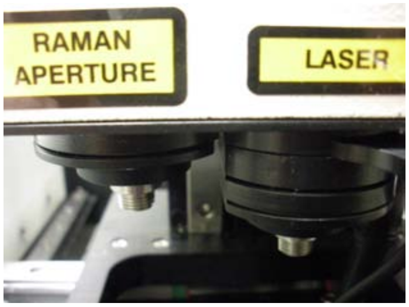


Photo 5: Raman probe head. (A) full view positioned for collection, (B) disconnected view, (C) bottom front, (D) base of probe head with fiber optic input port (center) and Raman collection port (left)

A

B

C



D

Photo 6: View of the laser focusing lens in line with the goniometer (blue arrow). For Raman collection, the probe head lens is positioned using remote control to be in line with the crystal.

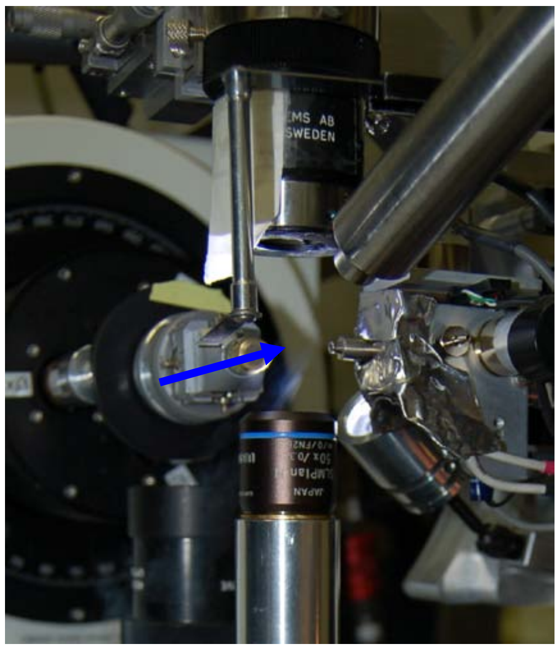


Photo 7: Spectrometer within the laser rack. Fiber optic attached is shown (arrow).