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Laser Safety Gram 0035 Advanced Radiographic Capabilities

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Disclaimer

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CERTIFIED LASER SAFETY OFFICER (CLSO)

Laser Safety Gram # 0035 *February 5, 2014*

TO: *Bruno van Wonterghem, NIF Operations Manager* *NIF-0175375-AB*

FROM: *Jamie J. King, Certified Laser Safety Officer*

SUBJECT: *Advance Radiographic Capabilities (ARC)*

This revision covers the addition of a short pulse alignment laser to the ARC Diagnostic Table (ADT).

The Advanced Radiographic Capabilities (ARC) is a diagnostic that can redirect up to four NIF beam lines (Q35T) through two compressor vessels, splitting each beam line into two beamlets, and generating up to eight distinct pulses with a pulse-width on the order of 10s of picoseconds (figure 1). The up to eight generated pulses will be staggered to back-lighter targets in order to create an x-ray movie of the compression phase leading up to ignition and other purposes.

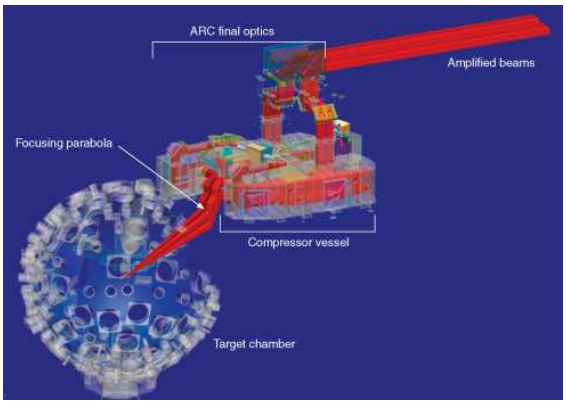

Figure 1. ARC Beam Path

These petawatt-class laser beams will be delivered to Target Chamber Center (TCC) as unconverted 1053nm (1ω) light. There are also other generally lower powered infrared lasers used in support of this diagnostic.

Due to increased cleanliness standards of the ARC, typical vendor procured laser safety curtains would not meet requirements and could not be used. This laser safety gram includes the report of testing cleanroom curtains that will serve as a laser barrier for the lower powered Class 3B lasers.

Scope of Laser Safety Gram

This laser safety gram evaluates the new hazards introduced by ARC laser sources and those presented to personnel working in and around any open ARC volume by existing NIF laser sources. ARC presents a complicated light hazard as its beam path extends from the Master Oscillator Room (MOR) to ARC via Q35T and from misdirected laser light downstream of the ARC from the Target Chamber (TC). ARC also requires the use of diagnostic tables on Level 3 of Switchyard 2 (SY2), referred to in this document as the ARC Diagnostic Table (ADT) and on Level 2 of Target Bay (TB), referred to in this document as the Parabola Vessel Diagnostic Table (PV-DT).

Laser Safety System Overview

Laser hazards for the ARC system fall into three areas.

1. In and around the area of the two ARC compressor vessels (CV1/CV2) when in an open configuration.
2. In and around the area of the PV-DT when in an open configuration.
3. In and around the area of the ADT in when in an open configuration.

This safety analysis will be broken into two segments:

1. Laser hazards to those personnel working in and around CV1/CV2, PV, PV-DT, and/or ADT or in the NIF originating from ARC.

2. Laser hazards to personnel working in and around CV1/CV2, PV, PV-DT, and/or ADT originating from the NIF.

There is also a hazard created from the new ARC beam path volume where laser light can be delivered through this volume into the TC and all the way back to the Laser Bays. A summary of controls can be found on in Table 2.

ARC Laser Sources

a. The Surface Defect Illumination (SDI) laser (Class 4, continuous wave (CW), 40W @940nm) is located in SY2:310. The light is fiber fed to the each CV and the PV and emits via light bars to check for damage on ARC gratings/mirrors. The SDI is similar to the Edge laser that is used for optic damage inspection. At the time of writing this LSG the use of this diagnostic laser is not certain.

b. The ARC diagnostic beam alignment laser (Class 3B, CW, 310mW@980nm) is located in SY2:310. The light is fiber fed to the CV1&2 launch platforms.

c. The ARC CV alignment laser (Class 3B, CW, 100mW@1053nm) is located in SY2:310. The light is fiber fed the CV1&2 launch platforms.

d. The ARC diagnostic table (ADT) alignment laser (Class 3B, CW, 100mW@1053nm) is located in SY2:390. The light is fiber fed to a launch on the ADT in SY2.

d1. The ADT short pulse alignment laser (Class 3B, Pulsed, 10nJ, 1053nm, 78MHz, 2.5E-13s) will be used for commissioning and is mounted to the ADT when used.

e. The ARC compressor commissioning laser (Class 3B, CW, 100mW@1045-1075nm) located in a portable rack in TB and is fiber fed to the CV1&2 launch platforms.

f. The ARC tilt sensor laser (Class 2, CW, 1mW@635nm) is located in SY2:390 and is fiber fed to the CV1&2 launch platforms.

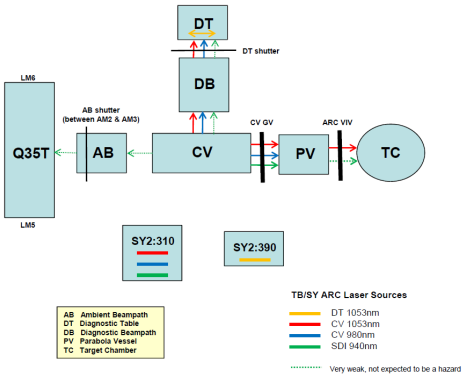

Figure 2. ARC laser sources showing hazardous paths

NIF sources to ARC

g. The NIF pulsed 1ω, 2ω, and 3ω beams that are propagated to target chamber center on "rod shots" (pulsed <10 J @1053nm (1ω), <1.4E-2 J @527nm (2ω) , <6.7E-4 J @351nm (3ω) in pulses of 0.2 to 30 E-9sec) and can be directed, reflected, or scattered into the ARC beam path volumes. These maximum energies are listed per beam line.

h. The NIF pulsed 1ω, 2ω and 3ω beams that are propagated to target chamber center on full-energy "system shots" (up to 2.19E4 J @1ω, 1.86E4 J @2ω, 1.31E4 J @3ω in pulses of 0.2 to 30 E-9sec) and can be directed, reflected, or scattered into the ARC beam path volumes. These maximum energies are listed per beam line.

i. NIF 1ω Input Sensor Package (ISP) alignment beams and main laser pointing and centering light sources (50-up to 500 mW CW).

j. NIF regenerative amplifier (regen) pulses (15–20 mJ, 1053nm, 1 Hz) (described in Laser Safety Gram #008, NIF 0092866).

ARC regen pulses (10mJ, 1053nm, 10Hz)

k. LCAL system operating at 532nm and 355nm (425mJ @532nm and 225mJ @355nm, 10 Hz, 3E-9 sec pulse length).

l. VISAR alignment laser (CW, 200 mW @ 660 nm) and a pulsed VISAR probe laser (up to 72 mJ @ 660 nm and 1000 mJ @1319 nm, 1.2 μsec pulse). (This laser is described in Laser Safety Gram #0022, NIF 0110618).

Other ARC Light Sources

An LED (SLED) source will be used to provide a fiducial for the AM7 mirrors. This LED source is 820nm ± 20nm "surface emitter" coupled to a 105/125um 0.22 N.A. fiber. There is an intended maximum nominal output of 10mW from the source. Though this is NOT a laser source, it does present a potential retinal hazard. For worse case analysis, this will be treated as a point source.

The source utilizes a 10mm biconvex lens with a focal length of 20mm. This configuration presents a very minimal nominal ocular hazard distance out of the end of the collimator of <10cm.

The only control required for this source is to label the ends of the output fibers from the source with, "Danger – Do not view end of fiber directly or with collecting optics – NOHD < 10cm. This control only applies to the output fiber out of the SLED source. There is no optical hazard after the splitters.

Laser Safety Analysis

Analysis of the optical hazard from ARC related laser sources followed by NIF optical sources will be covered here. Testing of proposed cleanroom curtain for use as a laser barrier is also included in this section.

Even though current plans do not anticipate deployment of the Class 4 SDI laser, an analysis of its hazard is included.

ARC Laser Sources

SDI Laser, source "a"
Wavelength - 940nm
Power - 40W
Beam size - 0.4mm
Divergence - 220mrad
Calculated required Optical Density (OD) – 4.6
NOHD - 0.67 meters out of light bar

ARC Diagnostic Beam Alignment, source "b"
Wavelength - 980nm
Power - 310mW
Beam size - 10.6mm
Divergence - 0.1mrad
Calculated required OD – 2.4

ARC CV alignment laser, source "c"
Wavelength - 1053nm
Power - 100mW
Beam size - 10.6mm
Divergence - 0.1mrad
Calculated required OD – 1.7

ARC-DT alignment laser, source "d"
Wavelength - 1053nm
Power - 300mW
Beam size - 1mm
Divergence - 0.1mrad
Calculated required OD – 2.2

ARC-DT short pulse align. laser, source "d1"
Wavelength - 1053nm
Power - 10nJ
Pulse length 2.5E-13
Rep Rate 78MHz
Beam size - 2mm
Divergence - 2mrad
Calculated required OD – 2.1

ARC CV commissioning laser, source "e"
Wavelength - 1045-1075nm
Power - 20mW
Beam size - 1mm
Divergence - 0.1mrad
Calculated required OD – 1.0

Taking into account the information above, typical 1ω laser protective eyewear (LPE) used in the NIF is sufficient to adequately protect against all laser sources ("a"-"e"). The NIF 1ω LPE also provides an OD>6.9 for wavelengths from 940-980nm. Laser source "f" is a Class 2 visible laser and requires no LPE (See Table 1).

For the purpose of this document, typical NIF 1ω eyewear is defined as:
OD>7@1053
OD>5@1045-1075
OD>6@940-980nm

The SDI laser is only an eye hazard up to 0.67 meters from the light bar. It is not required to be energized during normal maintenance activities in the CVs or PV, though typical NIF 1ω LPE provides adequate protection for this light source. For in-depth table of LPE requirements for each of the ARC laser sources see Table 2.

NIF sources to ARC

NIF sources "g" through "l" presents a hazard that may or may not be mitigated through the use of LPE. This section will analyze each and provide a recommendation to the use of engineering controls (LOTO, key tree, interlock, etc.) or LPE.

Rod shots – Source "g" is an optical hazard requiring "light-tight" enclosures from the laser bays to the TC. This is due to the fact that members of the general public along with untrained and unprotected workers may be present during rod shots.

There may be a need to have the PV door open to TB Level 2 during a limited number of rod shots for commissioning. LPE requirements are as follows: OD>3.5 @1053nm, OD>1.7 @527nm, OD=0 @351nm. To maintain "light-tightness" in the TB during rod shots, laser curtains and enclosures are required for this evolution.

System Shots – source "h" is an optical hazard requiring "light-tight" enclosures from the laser bays to the TC. All areas are exclusion zones "swept" during these shots. Therefore, engineered controls shall be required to prevent system shots during access to any ARC volume access.

NIF 1ω ISP light – access into beam-path volumes have been allowed with the use of normal NIF 1ω LPE for source "i". The specific requirement for this laser is OD>2.4 @1053nm. The laser is not a normally LOTO'd source, nor is it connected to any "key-tree". Other methods of control for this hazard include LOTO of valves and shutters which are covered in OSP581.11.

NIF/ARC regen – access into beam-path volumes for this source "j" is also allowed using the normal NIF 1ω LPE. The "worse-case" specific requirement for this laser is OD>0.9 @1053nm for access into any accessible volume and OD>4.2 @1053 at TCC. Other methods of control for this hazard also included the LOTO of valves and shutters which are covered in OSP581.11.

LCAL – source "k" has generally required either LOTO of the LCAL power supply or key tree for access into any accessible beam-path volume. This does not change for the purpose of this review. Access into any ARC volume shall require the use of key tree or LOTO of LCAL power supply "off" or closure and LOTO of valves and shutters which are covered in OSP581.11.

VISAR – as with LCAL, source "l" also has required LOTO of VISAR power supply or key tree for access into any accessible NIF volume. This is because the VISAR utilizes a wavelength that is not mitigated by normal NIF 1ω LPE. For ARC volume access, LOTO of the VISAR power supply "off" or use of key tree or closure and LOTO of valves and shutters which are covered in OSP581.11 is required. For an in-depth table of LPE requirements for each of the NIF laser sources see Table 3.

Clean Room Curtain Testing

Laser safety curtains are required to be used around the CV1/CV2 access doors and the PV-DT due the potential for hazardous laser light at these locations in an open configuration (figure 3). There is also a very strict requirement for cleanliness.

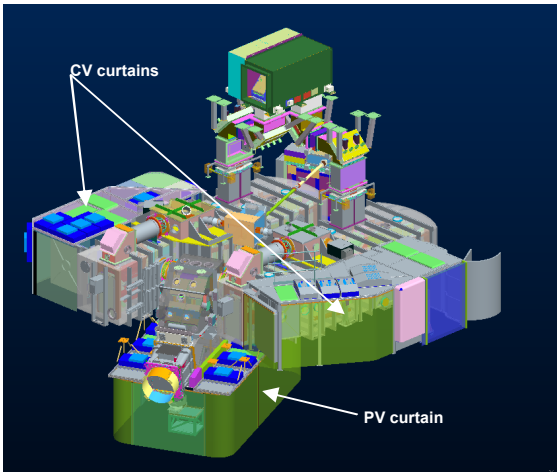

Figure 3. ARC vessels showing locations of curtains

Various commercially available laser curtains advertised as meeting both cleanliness and laser standards, but none met those essential for the cleanliness requirements of this application. It should also be mentioned that any curtain used must also meet the California State Fire Marshal Fire Certification as flame retardant.

A cleanroom fabric already used in the Facility and sold as PolySim 509 was proposed to be used. This material has been previously tested to meet the Facilities' fire code and cleanroom standards.

As the purpose of the curtain is only to serve as a secondary barrier, meant to capture any stray reflected light, and all alignment light used is <500mW, this material was given consideration. This is because generally a laser of <500 mW is not capable of burning or igniting a fire.

Dr. Mary Norton agreed to test a sample of the fabric at the SLAB Laser Lab located in B391. Two different types of fabric were tested, using the ANSI 136.7 *for Testing and Labeling of Laser Protective Material*. One was a single layered material and the other was dual layer with a metal foil sandwiched in between. Both a CW and a pulsed laser were used for this task.

Because the lasers being used for alignment operations in the ARC range between 980-1075nm, an infrared laser was chosen to perform the test. A CW (485mW, 1053nm) laser was used to expose the material for the required 100 seconds with a 1mm beam diameter. No indication of damage was visible even after a 30 minute exposure time.

A test was then completed using a pulsed (1053nm, 500mJ, 1.4E-8 seconds, 2Hz, 1watt average power) laser. Various square beam-sized were used (20mm, 10mm, 4.5mm). Again, a 100 second exposure was performed. Significant damage was seen to the material with the smallest beam size, but there was NOT complete burn-through (figure 4). Taking into account the results of the test, the curtain material may be used for the entryways to CV1/CV2 with all Class 3B alignment lasers (<0.5 watts).

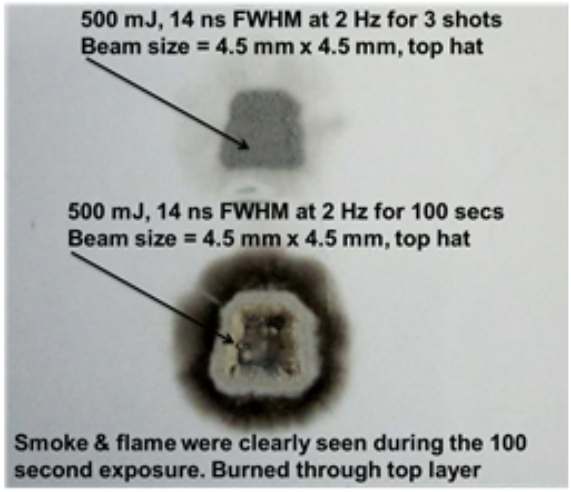

Figure 4. PolySim 509 Test Material

After testing was completed, a request to use the same curtain material around the PV-DT on Level 2 TB was made. For commissioning, there may be a need to bring rod shot light onto this table to collect data. As the curtain was not tested at this energy level, the curtain may only be used as a secondary barrier around the table.

A primary barrier of anodized aluminum or other material such as Alumalite™, shall be erected around the perimeter of the table as a beam edge guard. This barrier allows only scattering of any misaligned light off of the edge guard, thus preventing a raw beam from hitting the curtain. The barrier shall be inspected by the Laser Safety Officer prior to brining any rod shot light onto the diagnostic table.

Safety Summation

This section will detail the optical hazards located at each of the three designated locations (CV1/CV2, PV-DT, ADT) and recommended appropriate mitigation for all.

Compressor Vessels (CV1/CV2) – For the purpose of this review CV1/CV2 will be treated equally, as controls for one volume are the same as the other. CV1/CV2 will require access during both commissioning and maintenance activities. As described previously, potential laser light hazards are possible in these volumes from source *a* through *l*, except for source *f* (See Table 1).

For the ARC alignment sources (*a, b, c, f*), a potential exists for exposure to infrared laser radiation exceeding the Maximum Permissible Exposure (MPE) limits. This is true both inside of the CV1/CV2 volumes and outside of an open vessel (except source *a*) from a misdirected alignment beam. Mitigation for this hazard is as follows:

1. A curtain shall be erected surrounding the entrance(s) to CV1/CV2 for the purpose of a secondary barrier.
2. There are two separate access doors into each CV that shall have distinct controls.
    a. The "door closest to the TC" shall only be opened after the alignment light sources "b" through "e" have been LOTO'd off.
    b. The "door farthest from the TC" is required to be open during normal commissioning and alignment activities. Prior to opening this door, ALL of the following controls shall be in place:
        i. The corresponding CV curtain shall be pulled closed.
        ii. Laser Warning sign shall be in place at access point on curtain. Sign provided by Laser Safety Officer (LSO).
        iii. Flashing amber beacon shall be activated either locally, or from NIF Control Room (CR).
        iv. Typical NIF 1ω LPE shall be donned prior to entering the curtained area surrounding CV1/CV2.
3. Upon completion of the above, a request for permissives may be made to the CR to energize the ARC alignment lasers.
4. Two additional NIF source hazards are mitigated using the above control. They are:
    a. 1ω ISP
    b. NIF/ARC regen sources.

These sources are generally not LOTO'd off, but are adequately mitigated using typical NIF 1ω LPE.

5. The remaining NIF laser sources (PCS, PCU, LCAL, VISAR) shall be mitigated either through:
    a. LOTO of power supplies (OR)
    b. Use of key tree. (A separate key tree has been proposed for ARC use.)
    c. Other methods to mitigate these laser source hazards may be via isolation of the CVs through closure of shutters and/or valves. As the NIF light sources may enter into CV1/CV2 via both the LB and the TC sides of the volumes, both sides shall be isolated.
6. SIS redundant switches shall be located on the CV1/CV2 access doors. The switches are required to be made up in order to fire NIF sources "g" through "l".

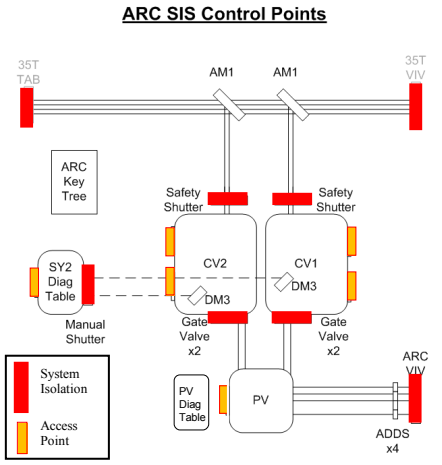

Figure 5. ARC beampath volumes showing control points

Using the "ARC SIS Control Points" diagram (figure 5), isolation of the LB side of the CVs may be completed via either:

- LOTO **BOTH** Q35T TAB and Q35T VIV Closed,

OR-

- LOTO affected CV Safety Shutter Closed.

Isolation of the TC side of the CVs may be completed via either:

- LOTO ARC VIV Closed,

OR-

- LOTO both affected CV/PV ARC Gate Valves Closed.

Parabola Vessel Diagnostic Table (PV-DT) – The PV has an access door located in the overhead of Level 2. As with CV1/CV2, the PV-DT access panel shall contain redundant SIS switches that must be made up in order to fire any NIF laser source "g" through "l".

During commissioning there is a requirement to bring PCS (Rod Shot) light onto the PV-DT. Current policy is that rod shots are only allowed when NIF is in a closed configuration, meaning that all enclosures and panels are closed up and "light-tight".

In order to allow rod shot light onto the PV-DT a bypass of the switches (using approved SIS bypass procedure), from the CR, will be needed along with implementation of the following controls:

1. The PV-DT curtain shall be pulled closed surrounding the PV-DT.
2. Beam edge guards shall be installed around the PV-DT to serve as a primary barrier for misdirected PCS light.
3. Laser Warning sign shall be in place at access point on curtain. Sign provided by Laser Safety Officer (LSO).
4. Flashing amber beacon shall be activated either locally, or from NIF Control Room (CR).
5. Typical NIF 1ω LPE shall be donned prior to entering the curtained area surrounding PV-DT.

Upon completion of the above, a request shall be made to the CR to bypass SIS on PV access door to allow PCS light onto PV-DT.

ARC Diagnostic Table (ARC-DT) – The ARC-DT is a vertically mounted optical table that is normally enclosed via interlocked "light-tight" panels. Laser source "d" is fiber fed onto the table. Laser source "d1" would be temporarily mounted on the ADT during commissioning of the temporal diagnostics on the ARC Diagnostic Table (or re-commissioning when a change needs to be made), and removed during normal operation.

There is also a beam path from CV1/CV2 used to bring sampled laser light onto the ARC-DT. This path can be isolated via a manual shutter located above the table.

During Commissioning and maintenance periods, there is need to access the ADT with laser light present. The following sources have been requested to be present on an open ADT:

- ADT alignment light
- ADT Short Pulse alignment light
- 1ω ISP
- NIF Regen

Due to the location, beam direction, and proximity of sources "d & d1" to the ADT manual shutter, it has been determined that they are not a hazard on the compressor vessel side of the manual shutter.

In order to operate with open ADT enclosure panels all of the following controls shall be implemented:

1. The ADT curtain shall be pulled closed surrounding the ADT.
2. Laser Warning sign shall be in place at access point on curtain. Sign provided by Laser Safety Officer (LSO).
3. Flashing amber beacon shall be activated either locally, or from NIF Control Room (CR).
4. Typical NIF 1ω LPE shall be donned prior to entering the curtained area surrounding ADT.

OR

1. LOTO ADT Manual Shutter closed
2. LOTO ADT CW alignment laser OFF
3. Ensure ADT short pulse alignment laser is removed from ADT

To prevent light sources “g”, “h”, “k”, and “l” from emanating outside of the ADT enclosure, permissives must be made up to fire these sources by either:

1. Install ADT enclosure cover panels

OR

2. LOTO closed the ADT manual shutter.

Cameras, Ports, and Misc. Connections

There are several locations on the ARC where cameras will be installed. For high neutron yield shots, these cameras are required to be removed quickly and efficiently. In order to accomplish this, a hinged, “light-tight”, enclosure cover (or similar), requiring a lock and key for removal, shall be installed over the cameras.

There are other enclosure locations where access may be required to attain measurements and to conduct testing or perform alignments. Some areas present a significant potential for ocular exposure to hazardous levels of laser radiation, where other have only a slight possibility of diffusely scattered exposure. Controls are implemented on a graded approach dependent on the probability of exposure.

Potential light hazards at all locations are:

- NIF Rod Shot
- NIF System Shot
- LCAL
- VISAR
- 1ω ISP
- NIF/ARC Regen
- 1053nm ARC CV alignment beam
- 980nm ARC CV alignment beam

The following describes these locations and recommended controls.

Level 4

SIDE Cameras (4 total) The SIDE Cameras are located at each ARC beamlet behind the AM3 mirrors. A fraction of light is allowed to leak through AM3 mirrors to the SIDE cameras.

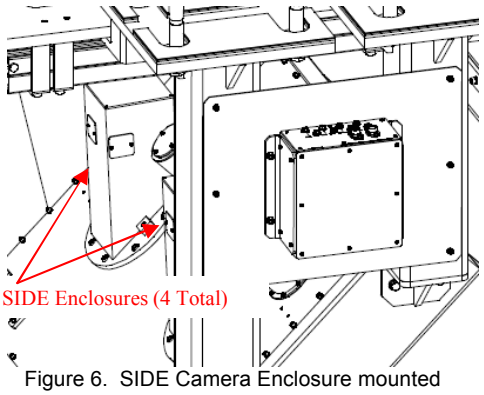

Figure 6. SIDE Camera Enclosure mounted

CV1&CV2 calorimeter and DM3 pointing and centering cameras (4 total) & DM5 pointing and centering cameras (2 total)- These enclosures are located on top of the CVs and require access from the 4th level.

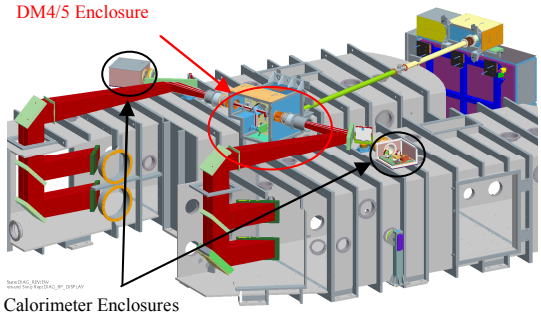

Figure 7. CV’s Showing DM4/5 and Calorimeter

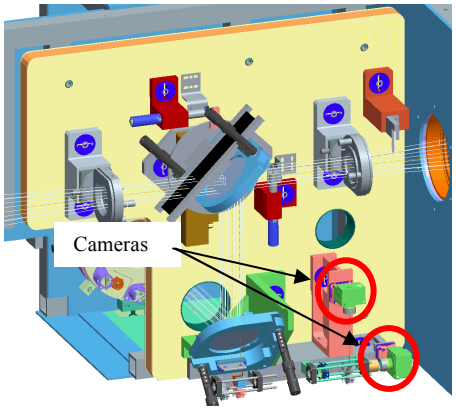

Figure 8. DM4/5 Enclosure

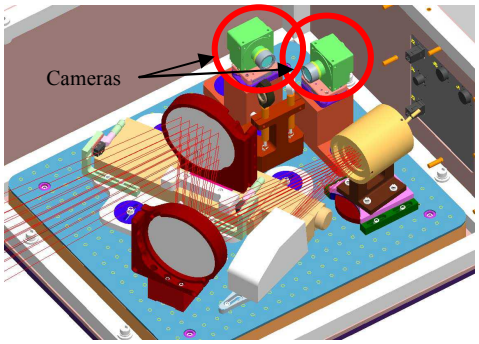

Figure 9. Calorimeter Enclosure

Level 3

980/1053nm pilot laser launch between CV1/CV2. This deals specifically with launches located between the CVs. There is a need to uncouple the fiber connections from the launch to check power output. Laser light from an uncoupled fiber here has a NOHD of <1m.

PV CAPS Cameras – (8 total) The CAPS Cameras located in 4 enclosures (2 cameras per enclosure) mounted on the sides of the PV. The cameras are accessed via sliding panels on the side of the PV.

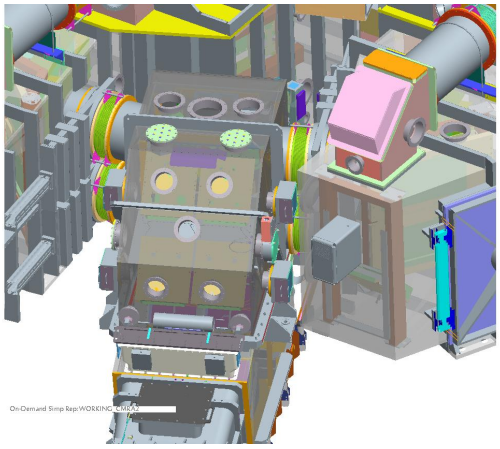
Figure 10. PV Showing CAPS Camera Enclosures

Tilt Sensor Cameras – These are located two on each side of CV1&2. These utilize Class 2, 635nm lasers for illumination and to check the functionality of the Basler cameras.

As no direct laser exposure is anticipated out of these enclosures, they shall be treated as a normal beam path access.

Controls

For all access:

- TB or ARC Key Tree
  -AND-
- LOTO ARC CV Alignment Laser OFF
  -AND-
- LOTO ARC Diagnostic Beam Alignment Laser OFF
  -AND-
- LOTO ARC CV Commissioning Laser OFF
  -AND-
- LOTO Q35T TAB, Q35T VIV, and ARC VIV CLOSED

-OR-

- TB or ARC Key Tree
  -AND-
- Erect laser barrier at enclosure to be opened. (Material approved by the Laser Safety Officer). Post laser warning sign and flashing beacon at entry point.
  -AND-
- Don NIF 1ω LPE

For removal of cameras ONLY immediately prior to yield shot

- TB or ARC Key Tree
  -AND-
- LOTO ARC CV Alignment Laser OFF
  -AND-
- LOTO ARC Diagnostic Beam Alignment Laser OFF
  -AND-
- LOTO ARC CV Commissioning Laser OFF
- Ensure TB has been swept clear of all nonessential personnel. (Either controlled by shot director in sweep mode or barricade and post laser warning signs on level 3 & 4). Post laser warning sign and flashing beacon at entry point.
  -AND-
- Instruct those remaining in TB to don NIF 1ω LPE prior to opening any camera cover.

For Access to DM4/5 or Calorimeter Enclosure for laser testing

- Control area <1m from rack.
- Don NIF 1ω eyewear
- Disconnect the 1053nm pilot beam fiber output in Rack SY2:310 and LOTO the fiber end with clamshell

  -AND-
- Set 980nm laser current/power so that power output at fiber launch is measured $\leq$ 1mW

  -AND-
- Remove the network connection to the 980nm laser and apply Admin Lock to clamshell cover on end of data cable

  -AND-
- Place "Notice" sign on controller "Do Not Adjust Laser Settings."

  -AND-
- Lock rack SY2:310 door closed and place "Warning" sign stating that "Authorized Personnel Only".

  -AND-
- Place NIF tour barricade and Warning sign on 4th Level near ARC

  -AND-
- Don NIF 1ω LPE prior to opening enclosure.

For removal of 980/1053nm fibers from fiber launch

- Control area within 1m of an open fiber end.
- Don NIF 1ω LPE prior to disconnecting the 980/1053nm fiber ends.

For removal of Tilt Sensor Cameras

- Follow normal beam path access controls (no light, except for Class 2 alignment light, is expected to directly escape).

All camera port covers shall be labeled with control information (label provided by the LSO). All other connections and covers shall be installed such that a tool is required for their removal. Labeling requirements shall comply with Laser Safety Gram #0025 *Policy on labeling NIF beampath enclosure access ports*.

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Jamie J. King
Certified Laser Safety Officer

Table 1 – ARC Laser Table.

LASERS TABLE (ARC) Jose Hernandez		2/14/2013	New			Calculation by Lazan 5.0 + manual (JJK initials) Form Rev. 07/29/2008															
Laser identification						Laser specifications								Direct eye exposure				Diffuse eye exposure			Skin exposure
ID #		Type	Make & Model	Comments	Class	Wave-length (nm)	Mode	Beam Size (mm)	Diver-gence (mrad)	Power CW (W)	Pulse Energy (J)	Pulse Length (s)	Pulse Rate (Hz)	Time (s)	MPE (W/cm^2)	NOHD fiber (m)	Min. OD	Time (s)	NOHD (m)	Min. OD @ 0.5 m	MPE for 10 s (W/cm^2)
ARC Sources																					
a	1	Diode	LIMO40-F400-DL940	SDI 0.22N.A.	4	940	CW	0.4	220	40	-	-	-	10	3E-3	5	4.6	600	0.65	0.2	6E-1
				Fiber Bar												0.65					
b	2	Diode	JDS Uniphase FG980	ARC Diag. Beam Align.	3B	980	CW	10.6	0.1	0.31	-	-	-	10	3.63E-3	0.78	2.4	600	5E-2	0	7.26E-1
c	3	Nd:YLF		ARC CV Align	3B	1053	CW	10.6	0.1	0.1	-	-	-	10	5E-3	0.35	1.7	600	3E-2	0	1.0
d	4	Nd:YLF	CrystaLaser	ARC Diag. Table Align	3B	1053	CW	1	0.1	0.30	-	-	-	10	5E-3	0.61	2.2	600	4.4E-2	0	1.0
d1	4a	Yb	High-Q IC 1053-250	ARC short pulse Align	3B	1053	Pulse	2.0	2.0	-	10E-9	2.5E-13	1E8	10	4.73E-3	-	2.1	600	<0.1	0	N/A
e	5	Diode		ARC Comp. Commission	3B	1045-1075	CW	1	0.1	0.02	-	-	-	10	4.9E-3	0.16	1.0	600	1E-2	0	9.8E-1
f	6	Diode		ARC Tilt Sensor	2	635	CW	1	1	0.002	-	-	-	0.25	2.55E-3	-	0.31	600	<0.1	0	3.11
	NIF Sources																				
g	Rod Shots	Nd:Gl	LLNL	Rod shot	4	1053	Pulsed	400x 400	<0.5	-	10	3E-10	Single Shot	Single Shot	1.95E-6	-	3.5	Single Shot	12.8	2.21	Undefined
		2w				527					1.4E-2				1.95E-7	-	1.7		<0.1	1.5	
		3w				351					6.7E-4				9.4E-4	-	0		<0.1	0	
h	Syst. Shot	Nd:Glass	LLNL	System Shot	4	1053	Pulsed	400x 400	<0.5	-	2.19E4	1-20E-9	Single Shot	Single Shot	5E-6	-	6.4	Single Shot	370	5.1	1E-1
		2w				527					1.86E4				5E-7		7.4		1.09E3	6.1	2E-2
		3w				351					1.31E4				3.3E-3		3.4		11.2	2.1	3.3E-3
i	1ω ISP	Diode			3B	1053	CW	1	0.1	0.5	-	-	-	10	5E-3	-	2.4	600	6E-2	0	1.0
j	Regen Amp.	Nd:Gl	LLNL	@TC Wall	3B	1053	Pulsed	290x 290			4.5E-3	1-20E-9	1	10	2.8E-6	-	0.3	600	<0.1	0	0.1
				@TCC				1									3.7				
	ARC Regen			@TC Wall	3B	1053	Pulsed	290x 290			10E-3	Min 0.5E-9 Max 2.0E-9	10	10	1.58E-5		0.9	600	0.5	0.5	Undefined
				@TCC				1									4.2				
Laser						Laser								Direct eye				Diffuse eye			Skin

identification						specifications								exposure				exposure			exposure
	ID #	Type	Make & Model	Comments	Class	Wave-length (nm)	Mode	Beam Size (mm)	Diver-gence (mrad)	Power CW (W)	Pulse Energy (J)	Pulse Length (s)	Pulse Rate (Hz)	Time (s)	MPE (W/cm^2)	NOHD fiber (m)	Min. OD	Time (s)	NOHD (m)	Min. OD @ 0.5 m	MPE for 10 s (W/cm^2)
k	LCAL	Nd:YAG	Surelite III		4	1064	Pulsed	9.5	0.6	-	0.850	4-6E-9	10	10	1.58E-5		6.2	600	4.1	1.9	1.0
						532					0.425	3-5E-9		0.25			6.5		9.3	2.6	2.0E-1
						355					0.225	3-5E-9		600	6.67E-4		4.6		0.3	0	6.67E-4
l	VISAR	Diode	Intelite	RS660-200	3b	660	CW	1	0.33	200	-	-	-	0.25	2.6	-	2.3	600	<0.1	0	200
		Nd:YAG	Continuum	0.12NA	3b	1319	CW	4	0.2	380	-	- 1.2E-6	- 1.1	10	40	0.2	1.4	600	<0.1	0	1000
					3b		Pulsed	4	0.4		1				2.42E-2	17.1	5.1		1.2	0.2	200
					4	660		4	0.2		7.2E-2			0.25	5.5E-4	30.3	5.6		2.9	0.9	40
					3b			1	1		2.4E-2				5.5E-4	17.5	5.1		1.7	0.5	40
		Diode	Bechtel Nevada	Comb Generator Dual Mode	3b	664	Pulsed	5E-2	0.29NA	-	3E-13	100ps	6E9	0.25	2E-3	0.0	0.0	600	<0.5	0.0	-
						780									1.22E-4						-
		Diode	MLS Lepton IV	New Alignment Laser	3B	660	CW	2.8 x 1.9	0.1	28.26	-	-	-	-	2.55E-3	-	1.5	600	<0.1	0	3.11
X	Misc	HeNe, diode	Various	Several	2-3B	400-700	CW	~1	> 0.42	≤ 1.5E-2	-	-	-	0.25	2.55E-3	-	≤ 1.2	600	< 0.1	0	2.0E-1

SPECIFIC COMMENTS:

WAVELENGTH: at which the laser is operated or capable of operating; **UV** < 400 nm, **VIS** 400 to < 700 nm, **IR** ≥ 700 nm, (**near-IR** ≥ 700 to < 1400 nm, **far-IR** ≥ 1400 nm).

LASER SPECS: typically listed for the smallest accessible beam size, highest power or pulse energy, shortest pulse length, and highest rep-rate.

EXPOSURE TIME: MPEs depend on the length of exposure. Use the actual pulse duration for single pulses; use the following (or greater) for CW or rep-rated pulses:

direct eye exposure: **UV** - 10-30,000 s (i.e., 8-hr work day) (depends on expected exposure time and assumes 2 successive days exposure); **VIS** - 0.25 s (i.e., blink response time) or at least 1/Hz; **all IR** - 10 s.

diffuse eye exposure: **UV** - 600-30,000 s (i.e., 8-hr work day) (depends on expected exposure time); **VIS or near-IR** - 600 s; **far-IR** - 10 s.

skin exposure: **all wavelengths** - 10 s.

MPE: Maximum **P**ermissible **E**xposure for unintentional, intrabeam (direct) exposures for the listed duration – typically in mW/cm^2 for CW or rep-rated (≥ 1 Hz) beams and mJ/cm^2 for single pulses at < 1 Hz. Purposeful direct viewing is not permitted unless authorized specifically in an IWS/SP.

OD: minimum **O**ptical **D**ensity eyewear (at the designated wavelength) for full protection to MPE levels. Optically aided viewing with telescopes, microscopes, cameras, etc. may require higher OD. **Note**: "alignment eyewear" for **visible beams 400-700 nm** may be used with an OD reduced by as much as 1.2 than specified in the "Min. OD" column (OD 1.2 is the equivalent to reduce a 15-mW HeNe to MPE level). Employ caution to avoid direct and stray beams. Since there is no aversion response to diffuse light, do not go below the OD level specified in the diffuse "Min. OD @ 0.5 m" column without LSO or IWS/SP-documented approval.

DIFFUSE EXPOSURES: based on 100% Lambertian reflection at normal incidence from a non-specular surface at a nominal arm-length distance of 0.5 m.

NOHD: Nominal **O**cular **H**azard **D**istance beyond which laser viewing is safe without eyewear (listed for fiber output and occasionally for unaided viewing of diffuse beams if warranted).

SUB-NANOSECOND: ocular calculations in the **VIS** and **near-IR** are based on ANSI Z136.1-2000. Present technology on laser safety eyewear causes the OD to be reduced significantly on femtosecond pulsed lasers, due to bleaching of the lens material. Laser eyewear may not provide adequate protection for sub-nanosecond lasers. Additional controls may be necessary to protect personnel from eye exposure.

SKIN MPE: "Unknown" means biological data is unavailable, and there is no known MPE for exposure times < 1ns.

Table 2 – Optical hazard introduced by ARC laser sources and recommended eyewear for normal operation.

	a. SDI	**b. ARC Diagnostic Beampath**	**c. ARC Compressor Vessel Alignment**	**d/d1. ADT**	**e. ARC commissioning**	**f. ARC tilt sensor**
	Class 4,CW, 40W@940nm	Class 3B, CW, 310mW@980nm	Class 3B, CW, 100mW@1053nm	Class 3B, CW, 100mW@1053nm Class 3B, Pulsed, 10nJ, 1053nm, 78MHz, 2.5E-13s).	Class 3B, CW, 100mW@1045-1075nm	Class 2, CW, 1mW@635nm
Target Chamber	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
ARC PV	OD> 4.6@940nm required when in vicinity (within 65cm) of fiber bar output.	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
ARC CV1/2	OD> 4.6@940nm required when in vicinity (within 65cm) of fiber bar output.	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
ADT	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
Level 2 PV DT	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
Q35 from safety shutter to 35T TAB to 35T TCVW (and IOM)	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
TB proper (i.e., outside of vessels)	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
Rest of SY/TB	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
SY2 RMDE and LB beam line	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
B35 PASS, RO/LI, TSF	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.

Table 3 – Optical hazard for ARC workers at designated locations.

	g. NIF rod shots	**h. NIF full power system shots**	**i. NIF 1ω ISP light**	**j. NIF/ARCregen amplifier**	**k. LCAL**	**l. VISAR**
	Pulsed <10 J @1053nm (1ω), <1.4E-2 J @527nm (2ω) , <6.7E-4 J @351nm (3ω) in pulses of 0.2 to 30 E-9sec	Pulsed up to 2.19E4 J @1ω, 1.86E4 J @2ω, 1.31E4 J @3ω in pulses of 0.2 to 30 E-9sec	CW 1053nm, 50-500mW	Pulsed 1053nm 4.5mJ, 1-20E-9sec, 1 Hz/ 10mJ, 1053nm, 0.5E-9sec, 10Hz	Pulsed 532nm, 355nm (220mJ, 190mJ) 3E-9sec	CW, 200 mW @660 nm Pulsed 72 mJ @ 660 nm and 1J @1319 nm, 1.2μsec pulse
ARC CV enclosure (Level 3) – with open enclosures.	Possible off-normal hazard, ensure enclosures closed at shot time.	Hazardous, ensure enclosures closed at shot time	OD>2.4 @1053nm	OD>4.2 @1053nm	OD 5.4@532nm OD 2.3@355	OD>2.3 @660nm OD>5.6 @660nm OD>5.1 @1319nm
ARC PV DT enclosure (Level 2) – with open enclosure.	Hazardous, ensure enclosures closed at shot time. Commissioning requires PV enclosure to be open. OD>3.5@1053nm	Hazardous, ensure enclosures closed at shot time	OD>2.4 @1053nm	OD>4.2 @1053nm	OD 5.4@532nm OD 2.3@355	OD>2.3 @660nm OD>5.6 @660nm OD>5.1 @1319nm
ADT enclosure (Level 3) – with open enclosures.	Hazardous, ensure enclosures closed at shot time	Hazardous, ensure enclosures closed at shot time	OD>2.4 @1053nm	OD>4.2 @1053nm	OD 5.4@532nm OD 2.3@355nm	OD>2.3 @660nm OD>5.6 @660nm OD>5.1 @1319nm

Table 4 - Recommended controls to allow safe working in areas into which the ARC sources have introduced a hazard. Orange shaded boxes indicate a LOTO or permissive control of a laser source is required to permit work. Yellow boxes indicate eyewear controls or optional LOTO in place of eyewear.

	a. SDI	**b. ARC Diagnostic Beampath**	**c. ARC Compressor Vessel Alignment**	**d. ADT**	**e. ARC commissioning**	**f. ARC tilt sensor**
	Class 4,CW, 40W@940nm	Class 3B, CW, 310mW@980nm	Class 3B, CW, 100mW@1053nm	Class 3B, CW, 100mW@1053nm Class 3B, Pulsed, 10nJ, 1053nm, 78MHz, 2.5E-13s).	Class 3B, CW, 100mW@1045-1075nm	Class 2, CW, 1mW@635nm
Target Chamber	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
ARC PV	OD> 4.6@940nm required when in vicinity (within 65cm) of fiber bar output.	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
ARC CV1/2	OD> 4.6@940nm required when in vicinity (within 65cm) of fiber bar output.	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
ADT	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
Level 2 PV DT	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
Q35 from safety shutter to 35T TAB to 35T TCVW (and IOM)	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
TB proper (i.e., outside of vessels)	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
Rest of SY/TB	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
SY2 RMDE and LB beam line	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.
B35 PASS, RO/LI, TSF	No additional hazard	OD> 2.4@ 980nm	OD> 1.7@ 1053nm	OD> 2.2@ 1053nm	OD>1.0@ 1045-1070	No additional hazard.

Table 5 – Recommended controls to allow safe working in the designated areas. Orange shaded boxes indicate a LOTO or permissive control of a laser source is required to permit work. Yellow boxes indicate eyewear controls or optional LOTO in place of eyewear.

	g. NIF rod shots	**h. NIF full power system shots**	**i. NIF 1ω ISP light**	**j. NIF/ARCregen amplifier**	**k. LCAL**	**l. VISAR**
	Pulsed <10 J @1053nm (1ω), <1.4E-2 J @527nm (2ω) , <6.7E-4 J @351nm (3ω) in pulses of 0.2 to 30 E-9sec	Pulsed up to 2.19E4 J @1ω, 1.86E4 J @2ω, 1.31E4 J @3ω in pulses of 0.2 to 30 E-9sec	CW 1053nm, 50-500mW	Pulsed 1053nm 4.5mJ, 1-20E-9sec, 1 Hz/ 10mJ, 1053nm, 0.5E-9sec, 10Hz	Pulsed 532nm, 355nm (220mJ, 190mJ) 3E-9sec	CW, 200 mW @660 nm Pulsed 72 mJ @ 660 nm and 1J @1319 nm, 1.2μsec pulse
ARC CV enclosure (Level 3) – with open enclosures.	Ensure enclosures closed at shot time, LOTO PCU, ARC Access Key Tree, 35T Tab, 35T VIV, ARC VIV, at other times when enclosures are open	Possible off-normal hazard, ensure enclosures closed at shot time, LOTO PCS, ARC Access Key Tree, 35T Tab, 35T VIV, ARC VIV at other times when enclosures are open	OD>2.4 @1053nm	OD>4.2 @1053nm	ARC Access Key Tree LOTO LCAL	ARC Access Key Tree LOTO VISAR
ARC PV DT enclosure (Level 2) – with open enclosure.	Possible off-normal hazard, ensure enclosures closed at shot time, LOTO PCS, ARC Access Key Tree, 35T Tab, 35T VIV, ARC VIV at other times when enclosures are open Commissioning – PV enclosure interlock bypassed, PV DT curtains closed, optical table edge guards in place, OD>3.5@1053nm	Possible off-normal hazard, ensure enclosures closed at shot time, LOTO PCS, ARC Access Key Tree, 35T Tab, 35T VIV, ARC VIV at other times when enclosures are open	OD>2.4 @1053nm	OD>4.2 @1053nm	TC Access Key Tree LOTO LCAL	ARC Access Key Tree LOTO VISAR
ADT enclosure (Level 3) – with open enclosures.	Ensure enclosures closed at shot time, LOTO ADT Manual Shutter when enclosures are open.	Possible off-normal hazard, ensure enclosures closed at shot time, LOTO PCS, ARC Access Key Tree, 35T Tab, 35T VIV, ARC VIV at other times when enclosures are open	OD>2.4 @1053nm	OD>4.2 @1053nm	TC Access Key Tree LOTO LCAL	ARC Access Key Tree LOTO VISAR

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