University Department/ School, and building	Warwick Centre for Ultrafast Spectroscopy RTP		
Room/area where work activity will be carried out	MAS 2.11	**Date of assessment**	12/4/2023
Risk assessment completed by, include contact details	Jack Woolley (RTP Manager) jack.woolley@warwick.ac.uk	**Name of appointed Laser Safety Officer**	Steven Leemoon

Background

This document, once completed and approved, constitutes a laser risk assessment for the work to which it relates. A laser risk assessment should be completed for each laser application at the University (except for those applications excluded by the University's Laser Safety Policy), before work first begins and when there are any significant changes to the work.

This is to satisfy the requirements of legislation, in particular:

- The Control of Artificial Optical Radiation at Work Regulations 2010 (AOR10); and
- The Management of Health and Safety at Work Regulations 1999 (MHSWR99)

and most importantly, to ensure that work with lasers is carried out safely. Even though the University has formalised a process for carrying out laser risk assessments, the onus is still on the researcher to demonstrate they have identified all the hazards and assessed the risks for their experiments. Laser risk assessments must be reviewed periodically or when an experiment significantly changes.

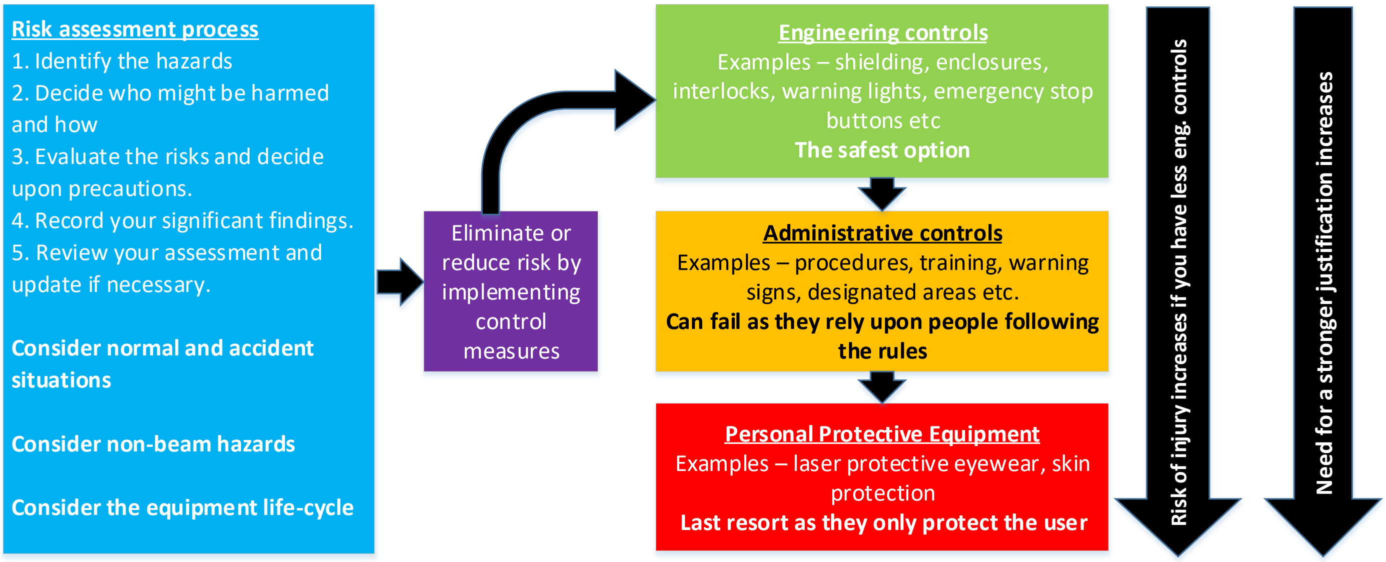
Scope of risk assessment	All work pertaining to the innolas *Picolo long* laser in MAS 2.11
Description of activity	Alignment, and general usage of the Picolo laser system in MAS 2.11. This includes, routine experimentation, alteration to the beam lines and optimisation of the system, and conversion of the output wavelength.
Reference to safety documentation (e.g. safe working procedures)	SOPs and other safety documents including more general risk assessments and SDS forms can be found in the red folder in the annex of MAS 2.11 and at go.warwick.ac.uk/WCUS

	Name	Title	Signature & Date	Review Date
Author	Jack Woolley	**RTP Manager**	**12/4/2023**	12/4/2024
Reviewer	Steven Leemoon	**Laser Safety Officer (LSO)**		
Approver				

Approved by Radiation Committee	**Date**

Process for carrying out risk assessment and selection of appropriate control measures

A risk assessment is a systematic examination of what, in your work, could cause harm to people, so that you can weigh up whether you have taken enough precautions or need to do more to prevent harm. When determining the control measures required to make the work safe, it is a legal requirement that the University follows the 'hierarchy of control measures', which places an emphasis on good equipment design and engineering controls before considering administrative controls (e.g. safe working procedures, training, warning signs) and personal protective equipment (laser protective eyewear). The flow chart below provides guidance on the process for carrying out risk assessment and the selection of appropriate control measures.



<table>
<tr><th colspan="4">Table 1 Description of laser application. (To be completed by risk assessor)</th></tr>
<tr><th>DETAIL</th><th colspan="3">INFORMATION</th></tr>
<tr><td rowspan="4">Description of laser application covered by this risk assessment</td><td rowspan="4">This risk assessment will cover all usage of the Picolo long laser in MAS 2.11. As open beams are necessary during normal operation, similar risks are anticipated throughout all parts of the laser system's life cycle.</td><td>Laser beam wavelength</td><td>1064, 532, 355, 266 nm</td></tr>
<tr><td>Type of laser
(e.g. e:Ne, CO_2)</td><td>ND:YVO^4</td></tr>
<tr><td>Output
(e.g. pulsed, continuous)</td><td>Pulsed, ≈800 ps, 1-5 kHz variable</td></tr>
<tr><td>Laser power or energy</td><td>400 mW Max</td></tr>
<tr><td>Part of 'Life cycle' covered (e.g. routine use, installation, maintenance)?</td><td colspan="3">Routine use. Maintenance carried out by the service engineer is covered under their own risk assessment.</td></tr>
<tr><td>Persons who may be affected by the use of this equipment</td><td colspan="3">Trained users of the research technology platform users, Staff, PhD students, PI's, Masters students, i.e. authorised users who have completed training ('Certificated') in laser safety awareness and or more comprehensive laser safety management. Auxiliary staff on as-need basis e.g. air-conditioning or fire alarm technicians, laser service engineers.</td></tr>
<tr><td>Could additional hazards arise during other parts of the life cycle?</td><td colspan="3">n/a</td></tr>
<tr><td>Is a risk assessment in place for other parts of the equipment life cycle?</td><td colspan="3">Laser service engineers work under their own risk assessments and method statements and therefore their activities are not covered by this document.</td></tr>
</table>

Laser compartment model

Laser applications will have hazards associated with the laser beam itself, as well as non-beam hazards (e.g. high voltages, laser fumes, high temperatures etc), which can often be more hazardous that the laser beam. This risk assessment must consider both the laser beam and the non-beam hazards. A systematic approach to identifying all the hazards is to use the laser compartment model, which splits a laser application into four compartments, as follows:

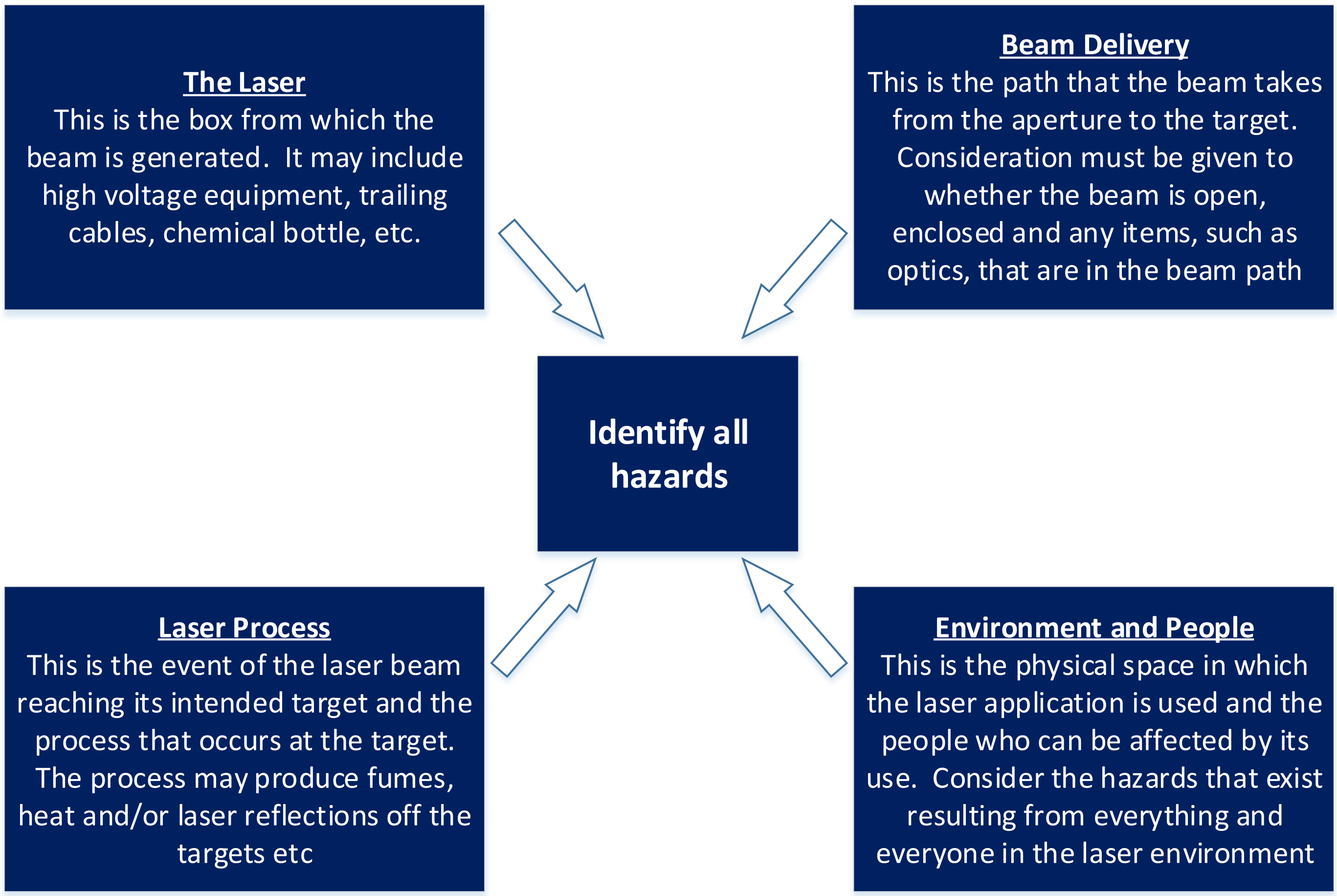


Table 2	Laser compartment descriptions (to be completed by risk assessor)	
Describe the laser and identify the hazards.		
DESCRIPTION	**HAZARDS**	
The laser is comprised of one module, and associated control electronics, connected through an umbilical cable. The control electronics are located above the laser on the gantry thus the umbilical cord is kept taught and is not a trip hazard.	High voltage ☒ Yes	Noise ☐ Yes
	Gas cylinders ☐ no	Trailing cables ☐ Yes
	Toxic gases/chemicals ☒ Yes	Other hazards ☒ Yes (Describe below) Open beams (after laser box) necessary during realignment – as such burning, blinding, and skin cancer hazards exist from laser exposure. Justification below in table 4
	Mechanical ☒ Yes	
Describe the beam delivery and identify the hazards (e.g. open or partially open beam, fully enclosed and interlocked?)		
DESCRIPTION	**HAZARDS**	
The beam is steered by flat optical components – where possible always in the horizontal plane. Where this is not possible. All beam lines are enclosed within black boxes. These are not interlocked as regular realignment is necessary when switching between wavelengths used, which happens on a daily basis. As such, open beams are required to undertake this realignment (justification in table 4). The need for daily realignment makes flight tubes impractical. Attenuation of the chosen output is possible by the in-built attenuator. However, once the power at which experiments are to be run is reached it is not practical to further reduce power, by means of an ND filter, for example.	Open or partially open beam ☒ Yes	Other hazards ☐ No
	Objects in beam ☒ Yes	
	Beam alignment carried out ☒ Yes	
	Variable beam path ☒ Yes	
What is the nominal ocular hazard distance (NOHD)?	See table at end of document	
Describe the laser process (e.g. what is the laser doing when it interacts with the target?)		
DESCRIPTION	**HAZARDS**	
In all the experiments, the laser is transmitted through a sample and then terminates on a spectrometer (CCD array, or pair of photodiodes). Any stray reflections are terminated on the side of the shielding or on beam blocks on the laser tables. Powers are kept low at the samples to prevent burning. Samples are enclosed in the shielding during experimental runs but will be open for initial beam alignment.	Laser fume ☒ Yes	Other hazards ☒ Yes (Describe below)
	Scatter from target ☒ Yes	
	Heating of target ☒ Yes	
	Manual handling of target ☒ Yes	
Describe the environment (e.g. wall and floor finishes, room access, windows, reflective objects, etc), and the people affected by laser use (including users, students, visitors, cleaners etc)		
DESCRIPTION	**HAZARDS**	
The lab has one entrance (and one emergency exit, kept locked) with a key code to enter, Appendix Figure 1. The front door is inside an Annex which requires card access for further security. The windows in the room and all blacked out. The floor is chemically resistant. The room is used by both laser users and non-laser users. It is necessary for non-laser users to have access	Dedicated laser room ☒ Yes	Unrestricted access ☐ no
	Windows in the laser room ☒ Yes	Out of hours access ☒ Yes
	Multiple doors ☒ Yes	Other hazards ☐ Yes (Describe below)

to the non-laser experiments in the room (we have no other room in which to house them), however, as an induction, all non-laser users are trained in operating within a laser lab, but only laser users are trained in operation of the laser itself. On top of that, the laser experiment is separated by a high-power resistant laser curtain such that the non-laser users are protected from exposure to the lasers. During open beam work and major realignment, non-laser users are excluded from the lab, the door is locked and extra signage is put on the lab door to indicate the situation. A laser warning sign is always in place when the laser is on and the main door is interlocked and magnetically sealed, so only those with a code can enter – users have 30 seconds to enter after defeating the interlock or the laser will be shuttered. The second door (for fire escape and large equipment movement) is interlocked with no defeating keypad so that when this door is opened the laser is shuttered.	Reflective objects present ☒ Yes	

Table 3		**Laser Risk Assessment** Each compartment should be assessed separately for both the beam and non-beam hazards identified in Table 2. The hierarchy of control measures must be considered when determining the control measures required.			
HAZARDS	**PERSONS AT RISK**	**EXISTING CONTROLS**	**RISK WITH EXISTING CONTROLS** (LOW, MEDIUM, HIGH)	**FURTHER CONTROLS REQUIRED**	**PLANNED DATE FOR IMPLEMENTATION**
The laser					
High Voltage	Users	Any high voltage is inside power supplies, which are properly grounded and contained. Users should never open these boxes, which requires several tools to do so. Only trained engineers working under their own procedures will ever access the high voltage.	Low	No	N/A
Trailing Cables	Users	There is only one cable from the laser to the control electronics, located above on the gantry. This arrangement keeps the cable from becoming a trip hazard and gives a clear workspace.	Low	No	N/A
Open beams	Users	There will be times when the beams after the laser box are open for alignment – this will be often as the wavelengths used change daily. PPE is supplied and all users are thoroughly trained. A laser SOP is in place, which details the procedures to follow when open beams are present (go.warwick.ac.uk/fac/sci/wcus/hands/sops/ultrafast/).	Medium	Constant update of training records and communication with users about maintenance schedules.	Ongoing

Table 3		**Laser Risk Assessment** Each compartment should be assessed separately for both the beam and non-beam hazards identified in Table 2. The hierarchy of control measures must be considered when determining the control measures required.			
HAZARDS	**PERSONS AT RISK**	**EXISTING CONTROLS**	**RISK WITH EXISTING CONTROLS** (LOW, MEDIUM, HIGH)	**FURTHER CONTROLS REQUIRED**	**PLANNED DATE FOR IMPLEMENTATION**
Beam delivery					
Open beams	Users	As described below, open beam work is necessary on all experiment tables. Shutters exist to ensure beams are only on the table when necessary. Beams are only open from the top down during alignment, otherwise they are contained by shielding on the edges of the table. All users are fully trained and all appropriate PPE is available. Beams are kept within the horizontal plane at all times on experiment tables.	Medium	Constant update of training and records.	Ongoing
Objects in beam	Users	The only objects that should ever be in the beam are the sample, which is open during alignment but contained during measurement, and beam blocks which are designed to absorb the beam and thus present minimal hazard. All controls that applied to open beams apply here too.	Medium	Constant update of training and records.	Ongoing
Beam alignment/ variable beam path	Users	All controls listed in the previous entries on open beams and objects in beam and in table 4 hold here also. The beam path is designed so that variation is kept to a minimum – this usually means minor adjustments on mirrors when wavelengths change. There are occasions when a beam will be directed from one beam path to another by way of swapping mirrors on magnetic bases. In these cases, SOPs exist to minimise risk, and after the initial change, again, beam alignment is minimal. (go.warwick.ac.uk/fac/sci/wcus/hands/sops/ultrafast/).	Medium	Constant update of training, records and practice.	Ongoing
Laser process					

Table 3		**Laser Risk Assessment** Each compartment should be assessed separately for both the beam and non-beam hazards identified in Table 2. The hierarchy of control measures must be considered when determining the control measures required.			
HAZARDS	**PERSONS AT RISK**	**EXISTING CONTROLS**	**RISK WITH EXISTING CONTROLS** (LOW, MEDIUM, HIGH)	**FURTHER CONTROLS REQUIRED**	**PLANNED DATE FOR IMPLEMENTATION**
Scatter from target	Users	Laser alignment is, wherever possible, achieved using a low scattering proxy target (for instance, a fluorescent dye which transmits or absorbs >90% of the beam, but fluoresces at safe power levels for visual alignment. Alternatively, alignment is achieved by redirecting the beam through an anodized pin hole or other target proxy, with only final fine adjustments taking place on the target itself. Highly scattering targets themselves are very rarely used as this would usually negate the efficacy of the experiment, which requires well transmitted light to observe.	Medium	Constant update of training, records and practice.	Ongoing
Manual handling of target	Users	SOPs outline that lasers should not be open when inserting and removing samples from the target area. Once alignment has been achieved, the target is kept enclosed along with the rest of the beam line (go.warwick.ac.uk/fac/sci/wcus/hands/sops/ultrafast/).	Low	Constant update of training, records and practice.	Ongoing
Environment and People					
Unauthorised access to the room	Unauthorised people	Unauthorised access is not possible as access is only via a card reader with card access only given to approved users. This user list does include users who haven’t passed the laser safety course. But they are restricted to the outside of the laser curtain and not exposed to any laser beams.	Low	Constant update of the approved user list	Ongoing
Damage to safety equipment	Persons in MAS 2.11	Regular checks of the relevant safety equipment (if laser enclosures are in-place and free from damage) are conducted by the RTP Manager.	Low	none	N/A
Fire	Persons in MAS 2.11 and building	No incendiary materials will be placed in the beam paths. In the event of a fire building SOP will be followed.	Low	none	N/A

Eye injury	Researchers in MAS 2.11	In the event of an eye injury campus security will be informed (by the researcher, another researcher in the lab, or the researcher's buddy) in order to contact 999. The injured researcher will be assisted to the nearest Ophthalmology unit (UHCW) by a combination of campus security, paramedics and the buddy.	Low	none	N/A
Out of hours working	Researchers in MAS 2.11	Out of hours working may be necessary on occasion – out of hours procedures will then be followed, which will include no lone working (buddy system), a minimum break of 11 hours between shifts worked and time off in lieu for the extra time worked. All building procedures for OOH working should be followed. In the event of an injury out of hours the buddy will help the researcher contact campus security and emergency services as needed.	Low	none	N/A

Justification of open beam work

Ideally, lasers of classification 3B and 4 should be fully enclosed with access panels interlocked to prevent access to the beam. Reliance should not be placed upon the wearing laser protective eyewear, unless absolutely unavoidable. If you are working with an open Class 3B or Class 4 laser beam, this will need to be justified and you need to show that you have considered the hierarchy of control measures. **Table 4 below must be completed**.

Table 4	
Are you working with a Class 3B or 4 laser that is not fully enclosed with access panels interlocked? (If yes please complete the sections below)	☒ Yes ☐ No
Have you considered the hierarchy of control measures? (If no, you must consider the hierarchy (see page 2 of this document) before commencing with the laser work.)	☒ Yes ☐ No
You must provide a justification for not being able to fully enclose the beam and prevent access. This justification must show that you have considered the options and that it is not practicable to implement these controls for your laser application. Just stating that you have trained operators who are familiar with lasers as your only justification is not acceptable	**Justification:** As the laser needs realigning from the final source output to the sample every time the wavelength is changed, which happens usually on a weekly basis, it is necessary to have constant easy access to the open beams for alignment. To implement engineering controls to keep the beam fully enclosed at all times would require automation of every optic in a long beam line – this would be in excess of 200 optics, and likely cost >£200k perhaps more. Therefore, a number of robust controls have been implemented to ensure that the risk is minimised, these are described both above and in this section. When partially open beam work must take place the following hierarchy of control has been considered: The Annex houses, all the available PPE (goggles) along with the lights showing which beamlines are in operation allowing users to take the appropriate/fit PPE before entering the facility. On entry there is a large solid board blocking direct viewing of the laser area, which prevents exposure to the area from the annex when the door is open. **Elimination and Substitution:** Elimination is not possible as the laser is necessary for experiments and final alignment must be done with the full power necessary to monitor true signal. Where possible, a lower power (through the use of the in-built attenuator) should be used for alignment. Where this is not possible the main laser should be run at its lowest possible power. **Engineering:** All lasers beam paths are kept in the plane of the table. An interlock system with a key code to allow entry exists on the door into the lab from the

	annex – card access is required to enter the annex. The tables are not fully interlocked as removal of lids occurs several times a day for small scale realignment of the beam when wavelengths are changed. As mentioned before, automating said alignment would be prohibitively expensive. A half-height laser curtain separates the ultrafast laser (class 4) beamlines from the static spectroscopy (class 2 or below) experiment table. The laser curtain can be pulled back only in short sections to allow entry into the laser area. It is suspended by strong metal chains from a strong metal pole and is held in place by long, thick strips of strong Velcro when the laser is in use. This keeps the curtain secure but allows for rapid egress in the event of an emergency. **Administrative:** All tools used are anodised to prevent stray coherent low divergence beams caused by tools in the beamline. All users are fully trained to be aware of and reduce hazards (**see open beam work risk assessment and SOPs**). Warning lights exist outside the lab to identify to users what beams are in use and thus what precautions need to be taken before entering the lab. The tables are compartmentalised so that only the smallest possible region has the lids open during alignment at a time. **PPE:** Laser goggles are supplied to all users when partially open beam alignment is taking place, on both sides of the curtain. All users are trained in checking the quality of the goggles and the facility manager checks these on a regular (monthly) basis as well. If any are damaged or need replacing, the facility manager is informed. All goggles are kept in their cases when not in use, both to ensure that they are not lost/are immediately available for the next user, and to protect them from damage. These goggles are colour coded according to the laser light being used for each experiment in the facility. It is not possible to reduce beam power to the point where beams are fully eye safe due to the extremely short pulse durations – please see MPE calculations attached which assume the highest power scenario. Even in low power cases, eye protection will be worn as if high power beams are in use. All eye protecting laser goggles have been supplied according to these MPE calculations. MPE calculations were done using the most restrictive possible parameters. In all cases this was for single ultrafast pulses. All goggles have been chosen to the highest available standard for pulsed lasers according to BS EN 207: 2009 regulations. A colour code system exists to aid users in the selection of appropriate goggles for their experiment. This is described in the laser use SOP.

MPE and NOHD values

Energy per pulse (µJ)	Frequency (Hz)	Radiant exposure (J/m2)	MPE_{single} (J/m2)	MPE_T (J/m2)	$MPE_{S.P\ Train}$ (J/m2)	Comparison with MPE (radiant exposure divided by MPE)	NOHD (m)
1064 nm							
84.3	1000	2.19	0.02	0.050	0.01	219	14.3
82.5	2000	2.14	0.02	0.025	0.0084	255	15.5
83.0	3000	2.16	0.02	0.017	0.008	270	15.9
82.5	4000	2.14	0.02	0.013	0.008	268	15.9
79.6	5000	2.07	0.02	0.010	0.008	259	15.6
532 nm							
35.0	1000	0.91	0.002	0.0254	0.002	455	20.8
34.0	2000	0.88	0.002	0.0127	0.002	442	20.5
33.0	3000	0.86	0.002	0.0085	0.002	429	20.2
31.3	4000	0.81	0.002	0.0063	0.002	406	19.6
28.4	5000	0.74	0.002	0.0051	0.002	369	18.7
355 nm							
22.5	1000	2.21	24	1.0	NA	2.21	0.25
21.0	2000	2.06	24	0.5	NA	4.13	0.53
20.0	3000	1.96	24	0.3	NA	5.89	0.73
19.8	4000	1.94	24	0.25	NA	7.76	0.92
18.4	5000	1.81	24	0.2	NA	9.04	1.03
266 nm							
11.5	1000	1.13	24	0.003	NA	377	9.47
11.3	2000	1.11	24	0.0015	NA	737	13.4
11.1	3000	1.09	24	0.001	NA	1090	16.5
10.6	4000	1.04	24	0.0008	NA	1390	18.6
9.20	5000	0.90	24	0.0006	NA	1510	19.4

Pulse length: 800 ps

Beam Diameter 3.6 mm

Beam Divergence 7 mrad

The limiting aperture for the eye for wavelengths between 400 and 1400 nm is 7 mm. The limiting aperture for the eye for wavelengths between 100 and 400 nm is 1 mm. As this is less than the actual beam diameter of 3.6 mm, the actual beam diameter will be used to calculate the beam area for these wavelengths.

MPET is the MPE for the average exposure time, which is taken as 10 s for the 1064, 355 and 266 nm beams and 0.25 s for the 532 nm beam.

For the 1064 and 532 nm beams, $MPE_{S.P.Train}$ involves multiplication of MPE_{single} by C5. For 532 nm C5 is equal to 1. For 1064 nm $C5 = 5xN^{-0.25}$ where N is the number of pulses in 10 s.

Eyewear protection factors

Wavelength (nm)	Glass eyewear	Plastic eyewear
1064	D LB5, M LB7	D LB5, M LB7
532	D LB4, M LB7	D LB4, M LB7
355	D LB4, M LB5	D LB4, M LB5
266	D LB8	D LB8

Appendix

Figure 1: Pictures of both entrances to the facility. Left shows the main entrance inside the annex with the magnetically interlocked door, warning light and appropriate signage. Right, shows the rear door to the lab (which is kept locked) with warning light and appropriate signage.