Gemini operational statistics

S. Hawkes *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

During the reporting year, April 19 – April 20, a total of 6 complete experiments were delivered in the Astra-Gemini Target Area and 2 experiments in TA2. In total 35 high power laser experimental weeks were delivered the Gemini Target Area and 25 weeks to TA2. The delivered schedule is presented in Figure 2.

The availability of the Gemini laser system (delivery to the Gemini Target Area) was 88% during normal working hours, rising to 140% with time made up from running out of normal working hours. The reliability of the Gemini laser was 92%. An individual breakdown of the availability and reliability for the experiments conducted is presented in Figure 1.

TA2 availability was 77% during normal working hours, rising to 123% with time made up from running out of normal working hours. The reliability of the Gemini laser was 84%

The high levels of total availability were made possible by the continued unique operational model employed on Gemini, which involves running the laser late into the evening. In addition, frequent weekend operational days were made available.

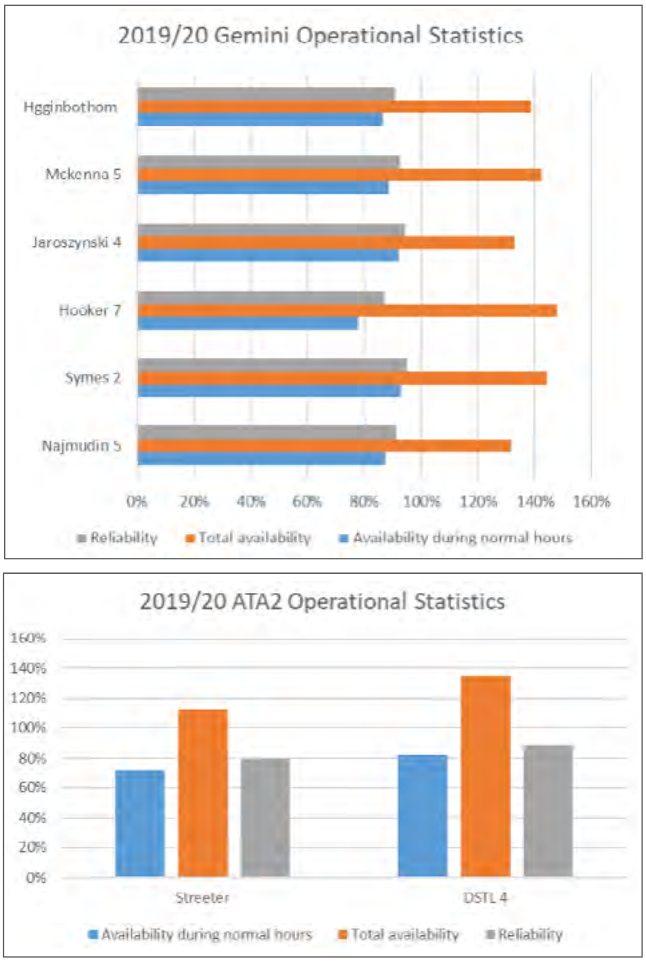


Figure 1: 2019/20 Gemini/TA2 operational statistics.

Week beginning	Gemini	TA2
01/04/2019	Set up	
08/04/2019		
15/04/2019		
22/04/2019	Najmudin	
29/04/2019	18110022	
06/05/2019		
13/05/2019		
20/05/2019	Maintenance	
27/05/2019	Symes	
03/06/2019	18210006	
10/06/2019	Set up	
17/06/2019		
24/06/2019		
01/07/2019	Hooker	
08/07/2019	18210006	Streeter
15/07/2019		18210012
22/07/2019		
29/07/2019	Extension	Extension
05/08/2019	Maintenance	
12/08/2019		
19/08/2019	Compressor installation	
26/08/2019		Streeter
02/09/2019		18210012
09/09/2019	Jaroszynski	
16/09/2019	18210027	
23/09/2019		Streeter
30/09/2019		18210012
07/10/2019		
14/10/2019	Extension	
21/10/2019	Maintenance	
28/10/2019	Set up	Streeter
04/11/2019		18210012
11/11/2019		
18/11/2019	Mckenna	
25/11/2019	18210005	Commercial access
02/12/2019		20110014
09/12/2019		
16/12/2019	Extension	
23/12/2019	Christmas	
30/12/2019		
06/01/2020	Electrical shutdown	
13/01/2020	Maintenance	
20/01/2020		
27/01/2020		Commercial access
03/02/2020	Higginbotham	20110014
10/02/2020	19210013	
17/02/2020		
24/02/2020	System access	System access

Figure 2: 2019/20 Gemini/TA2 operational schedule.

Contact: S. Hawkes (steve.hawkes@stfc.ac.uk)

Octopus and Ultra operational statistics

B. C. Bateman, M. Szynkiewicz, E. Gozzard, I. P. Clark, D.T. Clarke *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

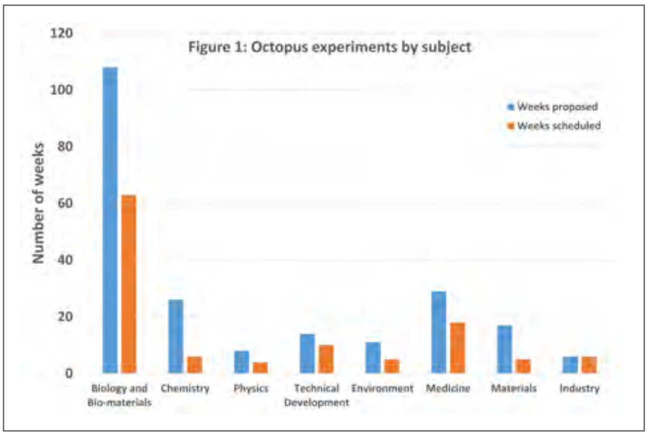
Octopus facility
In the reporting period (April 2019 to March 2020), 46 unique User groups submitted a total of 57 proposals bidding for time at the Octopus facility. 37 experiments comprising 85 weeks of access time were awarded to the UK User community throughout the year. A full breakdown of number of weeks applied for versus number of weeks scheduled is shown in Figure 1, indicating an oversubscription ratio of 1.71:1. Figure 3 shows that Biology and Bio-materials formed the majority of applications.

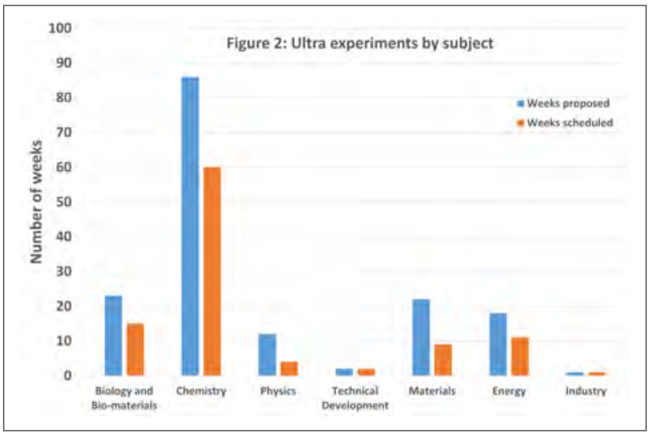
There were a total of 24 formal reviewed publications recorded throughout the year.

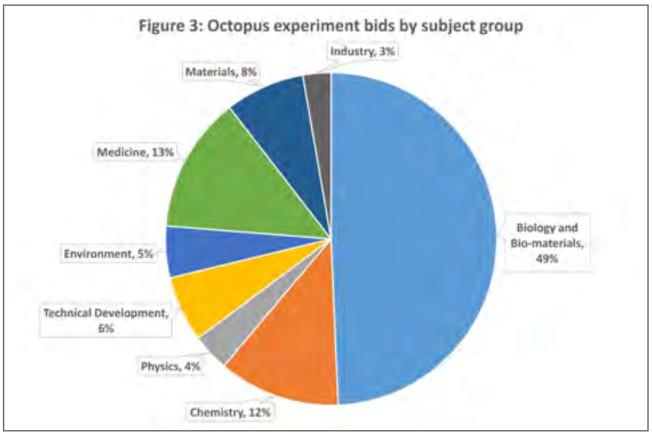
Ultra facility
In the reporting period (April 2019 to March 2020), 32 unique User groups submitted a total of 40 proposals bidding for time at the Ultra facility. 26 experiments comprising 61 weeks of access time were awarded to the UK User community. A full breakdown of number of weeks applied for versus number of weeks scheduled is shown in Figure 2, indicating an oversubscription ratio of 1.52:1. Figure 4 shows that Chemistry formed the majority of applications.

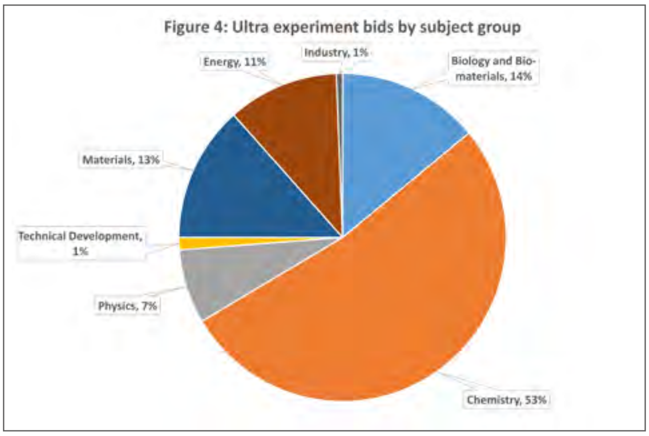
There were a total of 21 formal reviewed publications recorded throughout the year.

Octopus and Ultra availability
There was a total of 282 hours downtime reported over the combined 104 weeks of delivered access during this reporting period.









Contact: D.T. Clarke (dave.clarke@stfc.ac.uk)

Target Fabrication operational statistics

D. Haddock, C. Spindloe & M.K. Tolley *(Target Fabrication Group, Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

Experimental Support

This paper details Target Fabrication support given to experimental groups in the Vulcan target areas TAW and TAP, along with those in the Gemini Target Area, between April 2019 and April 2020. Target Fabrication supported five solid target Vulcan experiments and one solid target Gemini experiment, totalling 45 weeks of Vulcan access (plus training weeks) and 5 weeks of Gemini access. Additional experiments were also supported with filters and other diagnostic elements which are non-trivial but not reported on in these statistics. At 50, the total number of weeks supported is less than the previous year (60 in 2018-2019). The years previous to that were 71 weeks in 2017-2018, 56 in 2016-2017 and 57 in 2015-2016. This reporting period included the start of the national lockdown in response to the COVID-19 pandemic. Experiments scheduled for March were delayed and their analysis will be covered in subsequent reports.

The Target Fabrication Group also supports academic access experiments at AWE and internal activities run by facility staff; however, due to the low-level nature of support, it is not covered in this report.

Gemini and Vulcan target types are separated out when described in tables and graphics. Gemini targets are produced in arrays or tapes; with multiple shots available per object delivered, each position on the array or tape is referred to as an individual target. Quantifying such types alongside Vulcan single-shot targets disproportionately skews analysis. Gemini almost exclusively requires ultra-thin films which, although they are manufactured similarly to Vulcan targets, end up being used very differently in experiments.

1) Supported experiments

For the reporting year the total number of targets produced for each experiment is shown in Table 1. To better understand the amount of resources required for each experiment a classification of complexity is used:

- Class 1 Targets that require few resources and can typically be made with no specialist equipment with materials widely available from suppliers. Examples: i) micron thick foils, ii) wires glued to posts
- Class 2 Targets that require specialist manufacturing equipment and knowledge but manufacture is a well-established process in Target Fabrication. Examples: i) nanometre thick coatings, ii) multi-layered coatings
- Class 3 Targets that require long-term R&D and multiple technologies - also referred to as "high-specification targets". Examples: i) complex 3D assemblies, ii) foams, iii) structured MEMS coatings

The classification system and Table 1 show how Target Fabrication's resources were used throughout the reporting year. For example, the system can then be used to separate out experiments that use a high-number of targets requiring low amount of resource, compared with experiments that require multiple capabilities and resources to produce a few very high specification targets. The year saw a relatively even distribution of Class 3 experiments, which is in contrast to last reporting year in which two high-complexity experiments were concentrated in January and February. TAW experiments are typically complex with a higher proportion of their targets being Class 3. This is unsurprising because TAW experiments often use multiple probing beams from multiple angles, allowing 3D geometries to be investigated.

Experiment		Total Targets Produced	Class 1	Class 2	Class 3
VULCAN	0419 TAW	131	36	49	46
	0619 TAP	167	133		34
	0719 TAW*				
	0819 TAW	175	113		62
	1019 TAP	170	154		15
	1119 TAW	131	78		53
	Total	**775**	**514**	**49**	**210**
GEMINI	0419 GTA*				
	0619 GTA*				
	1119 GTA			2825	
	Total			**2825**	

Table 1: Targets produced by experiment and their relative complexity. (Class 3 targets have the highest complexity and Class 1 are the simplest targets to produce.)

**Specialist support given but no targets delivered.*

The total number of targets supplied to target areas at RAL by Target Fabrication this reporting period was 775 for Vulcan and 2825 for Gemini. The large number of targets delivered to Gemini can be explained by the 25 position mounting arrays. 113 arrays were delivered in total.

The number of high specification targets this year was 210 which is a reduction on the previous year's total of 323, but an increase on 119 in 2017-2018 and 98 in 2016-2017. The high number last year can be attributed to the particularly demanding 0319TAW experiment, which accounted for 190 high-specification targets.

2) Experimental Response

It is seen as a significant strength of Target Fabrication to be rapidly responsive to experimental results and conditions by working collaboratively with user groups. The Group responds to experimental changes during a campaign and often implements a number of modifications or redesigns to the original requests. The number of modifications and variations differs on each experiment and is dependent on the type of experiment and also on external conditions such as diagnostic and laser performance.

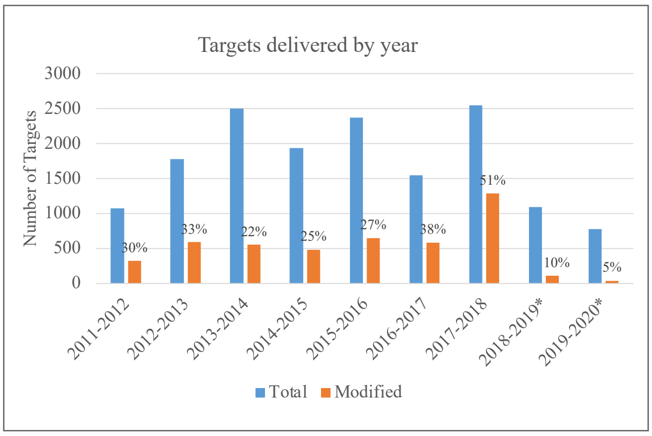


Chart 1: Total targets delivered by year showing the percentage that were modified from initial deliverables. Modified targets include any delivered targets that did not appear on the initial agreed target request.

**This reporting year and last only Vulcan targets are included. For Gemini no modifications were required to the 2825 targets delivered; thin film targets are pre-prepared and are therefore far less likely to be changed.*

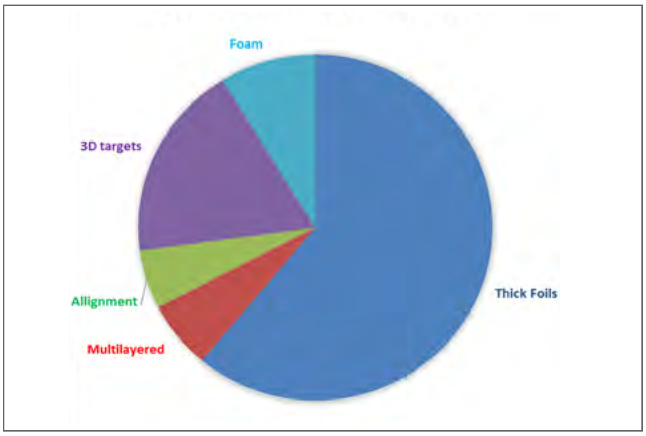


Chart 2: Target types (by number) for 2019-2020 delivered to Vulcan.

Target Fabrication's Quality Management System (QMS) ensures that there is tracking of all targets that are modified from the initial design. Modified targets include a) those that were delivered but not initially specified on the approved target list, b) modifications to approved designs, or c) completely new requests arising during campaigns. It is important to note that the capability to change designs can often ensure experimental success. For the reporting year the data on modified targets is shown in Chart 1.

Chart 1 shows that this reporting year and the previous had far fewer modified requests compared to previous years; good evidence that the experiments in this reporting year ran more-or-less in line with the target requests.

3) Target Categories

Targets can be separated into six main categories as shown in Table 2 and Chart 2.

Description of the types is as follows:

- Ultra-thin foil targets are specified as having a thickness <500 nm which require a coating capability and a skilled fabricator to process. Thick foils make up the rest of the >500nm single component foils
- Multilayer foils are stacks or layers of foils that require thin film coating capability to deposit multiple layers onto an existing foil; they are often different composition layers with different thicknesses
- Alignment targets are wires or pinholes that are used for set-up purposes
- 3D micro-structures are complex 3D geometries that combine multiple fabrication techniques with skilled assembly. Typically requires specialist micro-machining
- Foams are porous structures produced by novel chemistry techniques

Demand for high-specification 3D assemblies has been high for the past two years. This is the most challenging and time consuming target type which often incorporates multiple technologies such as micro-machining, coating and foams assembled into one object. Ultra-thin foils have been exclusively shot on Gemini this year with none requested on Vulcan which is the first time this has happened in recorded statistics.

It should be noted that Chart 2 is not a reflection of staff effort; assembly time for a single thick foil target is relatively short whereas for a batch of 3D targets R&D trials, manufacture and characterisation activities can amount to weeks of effort.

Target Category	2019-2020	2018-2019	2017-2018	2016-2017	2015-2016	2014-2015
Ultra-thin Foil	0	485	485	449	197	530
Thick Foils	472	2017	1208	743	1349	708
Multi-layered Foils	49	577	577	237	605	500
Alignment	42	2016	159	78	110	85
3D assemblies	142	73	73	38	99	82
Foams	68	2015	47	0	11	0
TOTAL	**775***	**2551**	**2551**	**1546**	**2371**	**1937**

*Table 2: Target type by year. *Only Vulcan targets are recorded in the totals. Gemini targets totalled 2825 for the year all of which were ultra-thin foils.*

Adapting to Demand

Experiments usually require similar targets with varying thickness, composition or geometry; for example, a thin foil experiment typically requests a thickness scan of a particular material. In such experiments each thickness or composition change requires a separate thin-film coating run. Experiments using 3D targets require a new assembly set up for every geometry change. Each new target thickness or geometry is designated a "unique variation". This reporting period within the 775 targets for Vulcan there were 110 unique variations which averages to nearly 7 targets per variation. Last reporting period the average number was 5 targets per variation, 7 in 2017-2018, and 7 in the two preceding reporting periods.

The number of targets per variation is a good measure of how complicated delivery is to an experiment. For example the 1019TAP experiment only required 15 different target iterations in the 170 delivered. One of those target iterations, "15um Gold foil on standard post", accounting for 152 targets. On the other hand 0419TAW required 32 iterations with 131 targets delivered. 0419TAW is a good example of an experiment that not only required a high quantity of Class 3 targets (see Table 1) but also many iterations in addition to the intrinsic target fabrication complexity. The flexibility provided by the Group to produce targets variations is a key capability of the CLF and enables the user community to fully utilize the limited time that is available during each experiment.

4) Waste Reduction

Unexpected delays or changes during an experiment often result in a number of targets that have been fabricated but that are not used by the end of an experimental campaign. Un-shot targets in this reporting period totalled 24 accounting for only 5% of the total targets made. The comparison with previous years can be seen in Chart 3. A value of 5% appears very low compared to previous years. An explanation for this could be that this reporting year saw few high-quantity low-complexity experiments. Low complexity experiments ask for more modifications because the targets are easier to change in an experiment. Also targets changes can be made if there are temporary issues with laser and diagnostic performance.

Any un-issued or returned targets are carefully sorted and high specification targets are stored under closely controlled conditions for potential use on future experiments. Where possible all spare target components and mounts are also stored for future use. The variety of mounts and components held in stock contributes to the Group's ability to adapt target designs quickly in response to experimental changes. Target Fabrication also continued to expand its 3D printing capability to manufacture the majority of target posts; both reducing costs and improving adaptability and responsiveness.

Targets that don't meet the user's requirements are recorded as non-conformities. Only 1 target was returned as non-conforming in the reporting period. The number is unlikely to be representative of the real non-conformity rate this reporting year and accurate ongoing recording

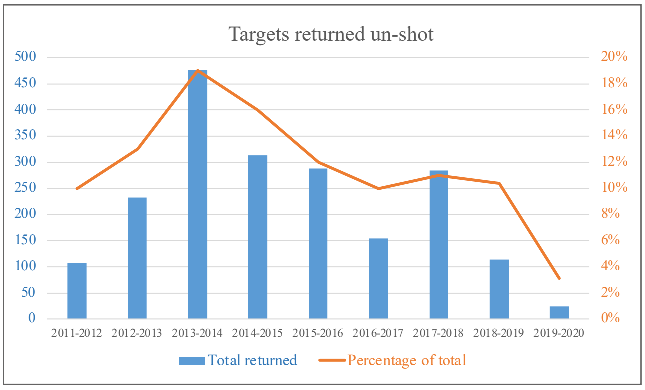


Chart 3: Total number of targets returned un-shot (in blue). The orange line shows the returned targets as a percentage of total targets delivered in that reporting year.

continues to be a challenge. In addition a number of internal non-conformities are found during the production phase which (obviously) are not issued to the user groups. It is a difficult metric to track; non-conforming targets might be recorded as "returned un-shot" or possibly targets will be un-used without notification to the Target Fabrication of the reason. Work is ongoing to ensure user groups record targets that do not meet their requirements as "non-conforming". However, the non-conformity rate is still expected to be low because Target Fabrication quality controls the targets before delivery as part of the manufacturing process. Target Fabrication update characterisation records of each target for the users to access during the experiment.

Orion Academic Access

The Target Fabrication Group has continued to support and supply targets to the Orion Academic Access campaign. In the reporting year targets were delivered to an experiment led by Queen's University Belfast investigating ion and neutron beam production. This experiment used a combination of ultra-thin foils and complex coil targets that required a large amount of fabrication time and effort. A final total of 64 complex targets were delivered and a number of targets were made during the experimental run which added resource demand. The targets required the integration of a range of complex assembly and characterisation capabilities across STFC including collaboration with the Technology Department for the manufacture of precision coils and Scitech Precision Ltd for the laser machining of target components.

External Contracts

Scitech Precision Ltd (a spinout company from the Central Laser Facility) provides high power laser targets and micro engineering solutions to the high power laser community and supplies targets, specialist coatings, laser machining services and consultancy across the world. In the reporting year 2019-2020 the company provided services to 32 individual institutions with a total number of contracts totalling 120. Of the contracts 55% were for high power laser targets, 34% for laser micromachining, 2% for phase plates, and 9% for target delivery system contracts. The spread of contracts is similar to the previous year with approximately one-third of the business being laser machining support for the Harwell Campus (including Diamond Light Source) and a number of spin out and spin in companies. Target contracts were delivered to large scales facilities including experiments carried out on the Orion laser at AWE, LMJ in France, SG-II in China and LLE in the US.

Summary

Target Fabrication has delivered targets to six experiments in the CLF this reporting year. Two experiments scheduled for March 2020 were rescheduled due to national lockdown and will fall into the scope of next year's report.

The total number of targets delivered to Vulcan is lower this reporting year than usual, in part because of the laboratory shutdown and also because there were no TAP experiments requiring low-complexity, high-quantity targets. Instead this year saw a marked increase in the number of high-complexity experiments spread across the year.

Target Fabrication has supported nine experiments in the CLF and twelve in other international facilities in the last year, as well as providing an increasing amount of characterisation services and acting as a knowledge base for target fabrication activities throughout Europe.

References

1. *D. Haddock, C. Spindloe & M. Tolley, Target Fabrication Operational Statistics, CLF Annual Report 2018-2019*
2. *D. Haddock, C. Spindloe & M. Tolley, Target Fabrication Operational Statistics, CLF Annual Report 2017-2018, p45-48*
3. *D. Haddock, C. Spindloe & M. Tolley, Target Fabrication Operational Statistics, CLF Annual Report 2016-2017, p48-50*
4. *D. Haddock, C. Spindloe & M. Tolley, Target Fabrication Operational Statistics, CLF Annual Report 2015-2016, p49-51*
5. *D. Haddock, C. Spindloe & M. Tolley, Target Fabrication Operational Statistics, CLF Annual Report 2014-2015, p58-60*
6. *D. Haddock, C. Spindloe & M. Tolley, Target Fabrication Operational Statistics, CLF Annual Report 2013-2014, p68-70*
7. *D. Haddock, C. Spindloe & M. Tolley, Target Fabrication Operational Statistics, CLF Annual Report 2012-2013, p74-75*
8. *D. Haddock, C. Spindloe & M. Tolley, Target Fabrication Operational Statistics, CLF Annual Report 2011-2012 , p71-72*
9. *H. F. Lowe, C. Spindloe & M. Tolley, Target Fabrication Operational Statistics, CLF Annual Report 2010-2011 , p76-77*

Contact: D. Haddock (david.haddock@stfc.ac.uk)

Vulcan operational statistics

A.K. Kidd *(Central Laser Facility, STFC Rutherford Appleton Laboratory, Harwell Campus, Didcot, UK)*

Introduction

Vulcan has completed an active experimental year, with 31 full experimental weeks allocated to target areas TAW and TAP between April 2019 and March 2020; the schedule was interrupted in March 2020 due to Covid-19. Table 1 shows the operational schedule for the year, and reports the shot rate statistics for each experiment.

PERIOD	TAW	TAP
	2019	
22 Apr – 26 May	L Antonelli *High resolution phase contrast imaging of strong shock-cloud interactions* (74, 26, 64.9%) (85.3%, 104.2%) (5 weeks) 18210019	
01 Jul / 24 Jun – 28 Jul	N Woolsey *Measuring the dynamics of magnetic fields in high energy-density plasmas* (56, 9, 83.9%) (89.6%, 109.8%) (4 weeks) 18110017	M Borghesi *Irradiation of 3D cell models with high-flux, high-energy laser-driven protons* (139, 10, 92.8%) (87.6%, 103.8%) (5 weeks) 18210022
26 Aug – 06 Oct	F Keenan *Generation of high photoionization parameter plasmas to simulate accretion-powered astronomical X-ray sources* (133, 5, 96.2%) (83.0%, 113.9%) (6 weeks + 2 day overrun) 18210003	
28 Oct – 08 Dec / 01 Dec	P Norreys *Monoenergetic ion beam from collisionless shocks* (64, 18, 71.9%) (87.7%, 112.0%) (6 weeks) 18210002	M Borghesi *Sub-lethal effects of proton irradiation of cellular media at ultra-high dose rate* (187, 34, 81.8%) (86.5%, 126.6%) (5 weeks + 3½ day overrun) 19210020
	2020	
02 Mar – 05 Apr	C Palmer **Laboratory investigation of dust charging and destruction in shocked plasma** (Experiment interrupted due to Covid-19) 19210011	D Carroll *Investigation of EMP emissions for understanding the source mechanisms and the rules for tuning and employing them in high power lasers* (Experiment interrupted due to Covid-19) 19210019

Table 1: Experimental schedule for the period April 2019 – March 2020.

(Total shots fired, failed shots, reliability) (Availability normal, additional hours)

Numbers in parentheses indicate the total number of full energy laser shots delivered to target, followed by the number of these that failed and the percentage of successful shots. The second set of numbers are the availability of the laser to target areas during normal operating hours and including outside hours operations.

The total number of full disc amplifier shots that have been fired to target this year is 653. Table 2 shows how this figure compares with that for the four previous years. 102 shots failed to meet user requirements. The overall shot success rate to target for the year is 84%, compared to 91%, 90%, 86% and 81% in the previous four years. Figure 1 shows the reliability of the Vulcan laser to all target areas over the past five years.

Year	No of shots	Failed shots	Reliability
15–16	1143	108	91%
16–17	948	93	90%
17–18	934	132	86%
18–19	607	113	81%
19–20	653	102	84%

Table 2: Shot totals and proportion of failed shots for the past five years.

The shot reliability to TAW is 82%, up 2% from the previous year. The shot reliability to TAP is 84% - down from 86% in 2018-19.

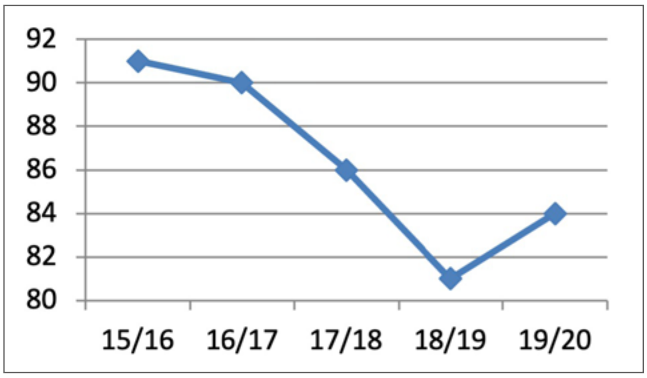


Figure 1: All areas shot reliability for each year 2015-16 to 2019-20.

Analysis of the failure modes reveals that the overriding causes of failed shots are beam alignment, front end related issues and triggering. The first two causes are manifested in low or high energy output of the rod amplifier chain (outside of +/-20% of the requested energy). Instability in the pulse energy is introduced during propagation from the front end room to the laser area> Novel methods of beam stabilization are being investigated to improve this fault mode.

There is a requirement which was originally instigated for the EPSRC FAA that the laser system be available, during the five week periods of experimental data collection, from 09:00 to 17:00 hours, Monday to Thursday, and from 09:00 to 16:00 hours on Fridays (a total of 195 hours over the five week experimental period). The laser has not always met the startup target of 9:00 am but it has been common practice to operate the laser well beyond the standard contracted finish time on several days during the week. In addition, the introduction of early start times on some experiments continues to lead to improvements in availability.

On average, Vulcan has been available for each experiment to target areas for 86.7% of the time during contracted hours, compared with 85.1% for the previous year. The overall availability to all target areas has remained constant at 112.6% compared with 112.9% in 2018-19. The time that the laser is unavailable to users is primarily the time taken for beam alignment at the start of the day.

Contact: A.K. Kidd (andy.kidd@stfc.ac.uk)