Operational Statistics

Gemini

During the reporting year, April 2023–April 2024, a total of six complete experiments were delivered in the Astra-Gemini Target Area. In total, 31 high power laser experimental weeks were delivered to the Gemini Target Area. The delivered Gemini schedule is presented in Table 1.

Table 1: Gemini 2023/24 operational schedule.

Week Commencing	Activity
7 January	**Hooker** 2221009
14 January	
21 January	
28 January	
4 Feburary	Extension
11 February	N/A
18 February	Pump laser service
25 February	Gas alarm replacement
3 March	N/A
10 March	**Kettle** 22210012
17 March	
24 March	
31 March	
7 April	
14 April	N/A
21 April	**PoC experiment** 23315000
28 April	
5 May	N/A
12 May	N/A
19 May	Beamline set-up
26 May	
2 June	**Jaroszynski** 22210025
9 June	
16 June	
23 June	
30 June	

Week Commencing	Activity
7 July	N/A
14 July	N/A
21 July	N/A
28 July	**Doria (EU)** 22210024
4 August	
11 August	
18 August	
25 August	
1 September	N/A
8 September	N/A
15 September	N/A
22 September	Christmas break
29 September	
6 October	
13 October	N/A
20 October	N/A
27 October	N/A
3 November	N/A
10 November	**Sarri** 23210006
17 November	
24 November	
1 December	
8 December	
15 December	Configuration changes Beam stabilisation
22 December	
29 December	
5 January	

The availability of the Gemini laser system (delivery to the Gemini Target Area) was 85% during normal working hours, rising to 131% with time made up from running out of normal working hours. The reliability of the Gemini laser was 89%. An individual breakdown of the availability and reliability for the TA3 experiments conducted is presented in Figure 1.

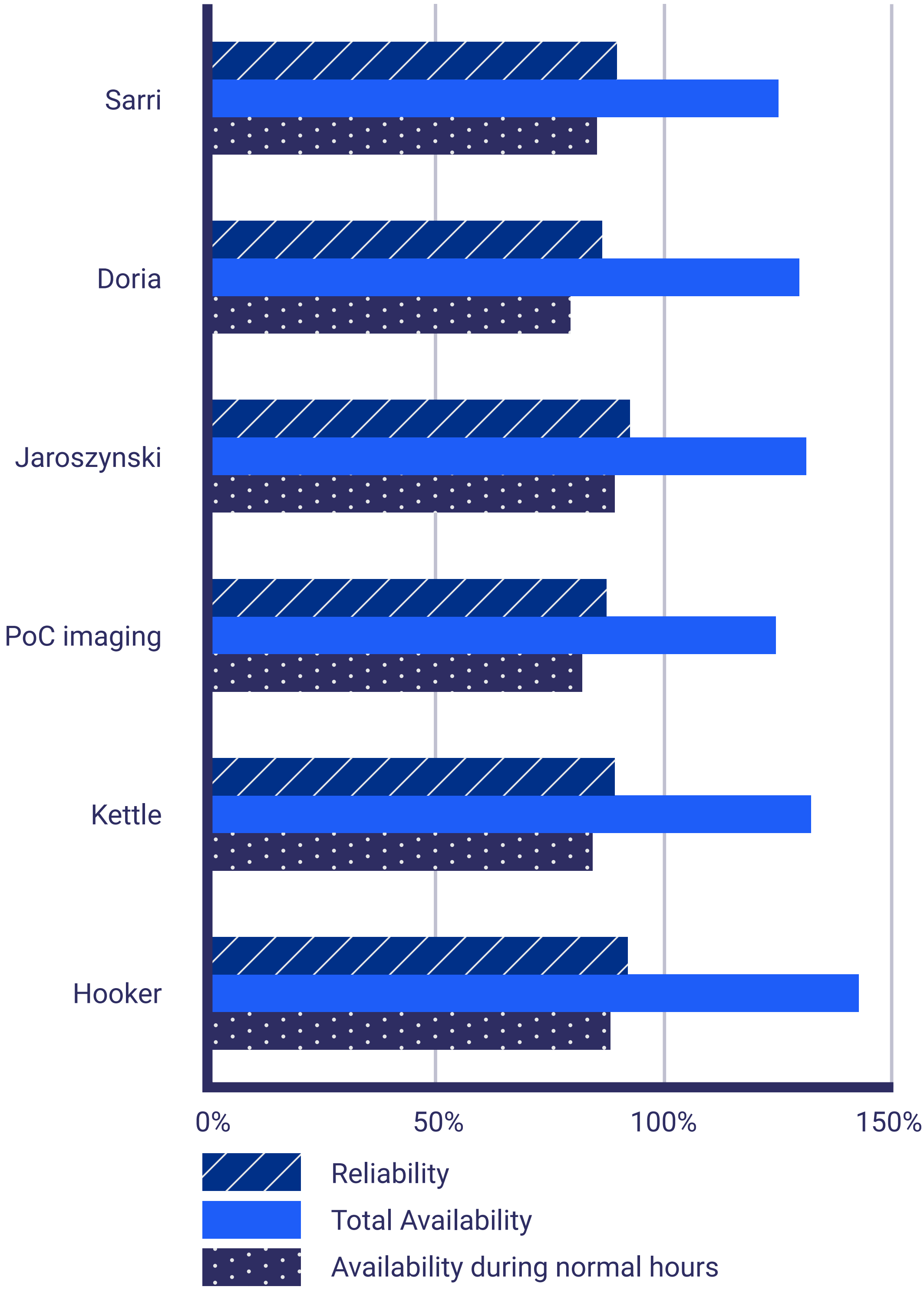

Figure 1: 2023/24 TA3 Operational statistics.

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.

Author: S. Hawkes

Lasers for Science Facility

Artemis facility

During this reporting period, the UK User Community applied for 74.5 weeks of peer-reviewed access to the Artemis facility, of which 29 weeks were awarded, representing an over-subscription ratio of 2.57. A total of five unique user groups performed six scheduled experiments. Figure 2 shows that atomic, molecular and optical were the most popular experiment subjects conducted.

4.08 weeks of downtime and 22.36 of additional weeks of access were reported for the scheduled experiments, corresponding to a total of 35.17 weeks access time delivered to the User Community. A total of two formal reviewed publications were recorded throughout the year.

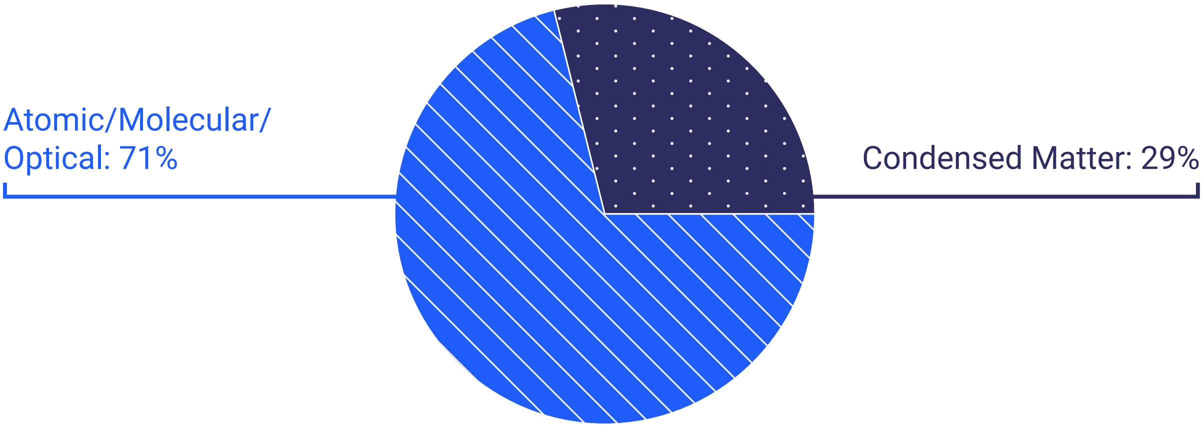

Figure 2: Artemis experiments by subject

Octopus facility

During this reporting period, the UK User Community applied for 167 weeks of peer-reviewed access to the Octopus facility, of which 90 weeks were awarded, representing an over-subscription ratio of 1.86. A total of 22 unique user groups performed 27 scheduled experiments. In addition, 16 days proof of concept experiments, 1 day of development and 49 days of commercial access were delivered. Figure 3 shows that Biology and Bio-materials were the most popular experiment subject conducted.

27 hours of downtime were reported. A total of 13 formal reviewed publications were recorded throughout the year.

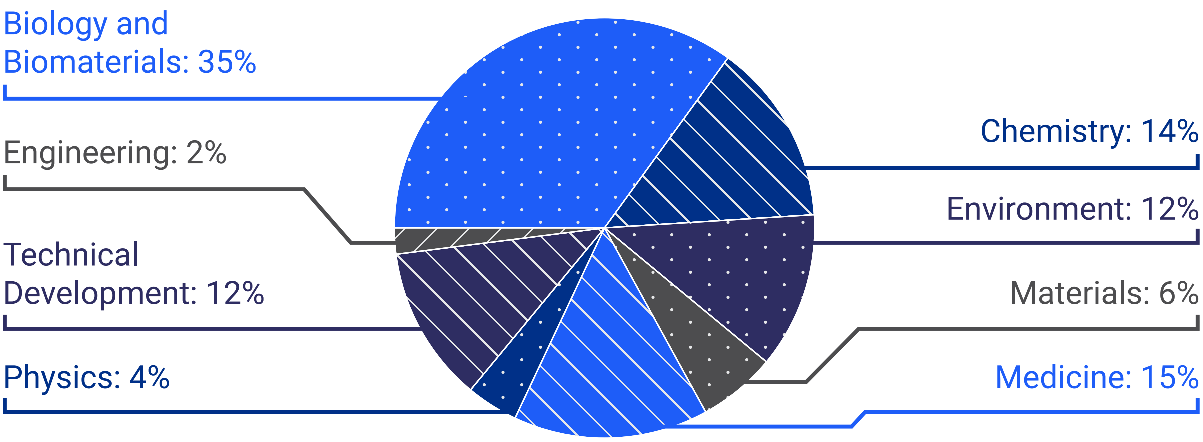

Figure 3: Octopus experiments by subject

Ultra facility

During this reporting period, the UK User Community applied for 76 weeks of peer-reviewed access to the Ultra facility, of which 50 weeks were awarded, representing an over-subscription ratio of 1.52. A total of 15 unique user groups performed 20 scheduled experiments. In addition, seven days proof of concept experiments and six weeks of commercial access were delivered. Figure 4 shows that Chemistry was the most popular experiment subject conducted.

145 hours of downtime and 587 additional hours of access were reported. A total of 22 formal reviewed publications were recorded throughout the year.

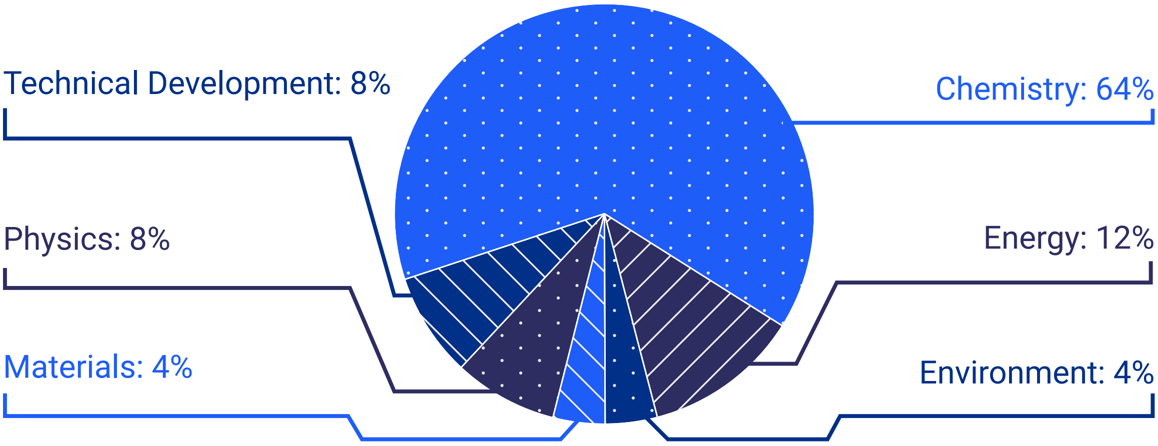

Figure 4: Ultra experiments by subject

User satisfaction feedback

Surveys completed by user groups after their experimental time indicate an average satisfaction rating of 91.6% over the five specified categories.

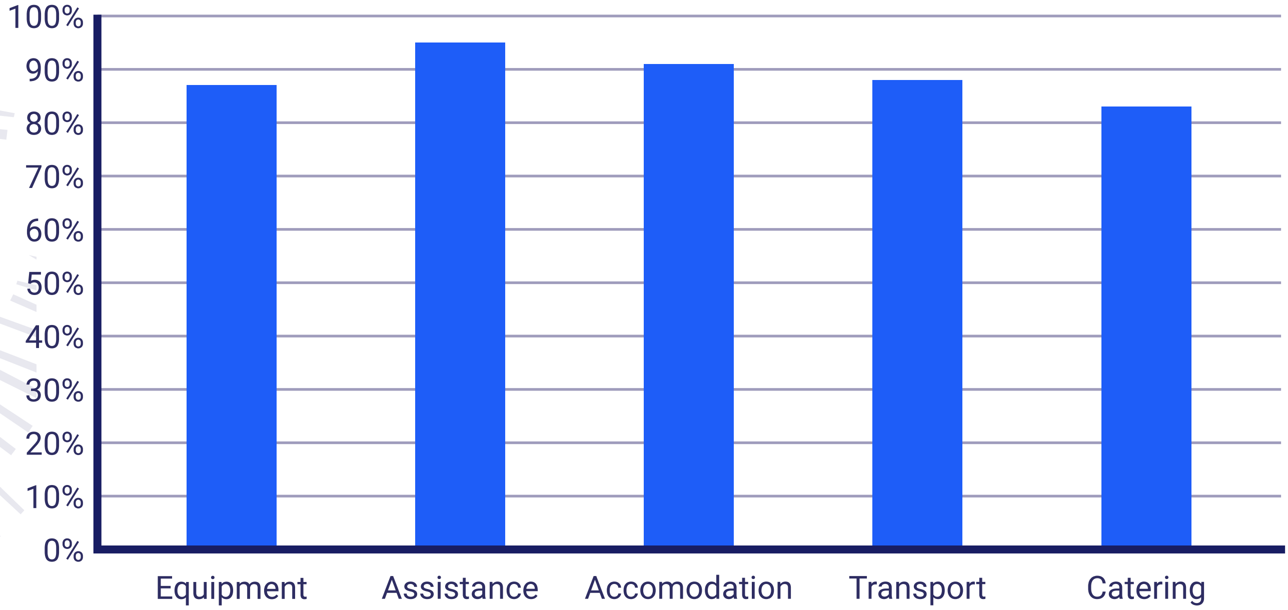

Figure 5: Average user satisfaction

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Target Fabrication

This report details the target delivery of the Target Fabrication group for High Power Laser (HPL) experiments at the Central Laser Facility over the period spanning April 2023–March 2024, as well as showing historic target supply trends for reference. The Target Fabrication group provides a multitude of target components, technologies and characterisation services crucial to the success of the HPL programme. Following the shutdown of the Vulcan target areas in October 2023 in preparation for the Vulcan 20-20 upgrade, the group is offering "Vulcan Dark Period" support and is tasked with the manufacture of targets for Vulcan-aligned experiments conducted at other facilities.

Over the 2023/24 operating period, the Target Fabrication group provided targets for 12 experimental campaigns–five based on the Gemini laser, three on Vulcan TAW and one on Vulcan TAP at the CLF, along with two Vulcan Dark Period experiments at ZEUS-Michigan and ELI-NP, and one External Access campaign at Orion, AWE.

The vast majority of targets that the group manufactures are solid targets, although multi-component gas cell targets are regularly delivered. With the EPAC facility being commissioned in 2025, ultimately requiring 1–10 Hz target solutions, a liquid targetry system is in development giving the ability to create sub-micron films of deionized water as a high repetition rate target or plasma mirror solution. As such, the Target Fabrication group will be equipped to deliver targets comprising solid, liquid or gaseous media.

A solid target comprises virtually any material (metals, polymers and ceramics), coated to nanometrically precise thicknesses in a range of geometries and characterised to micron-scale precision to ensure they fall within tight tolerances. There is generally a difference between the type of target requested for Vulcan and those for Gemini experiments. Vulcan targets are typically more complex (for example single target assemblies on posts) with a focus on precision-assembly 3D microstructures and mass-limited targets. Gemini targets are typically less complex and more mass-manufacturable to accommodate the higher repetition rate of the laser. Typical Gemini targets include multi-layer or ultra-thin foils on arrays or tape substrates.

Supported Experiments

The 12 experimental campaigns supported over this operating period, along with a summary of the main target types requested, are shown in Table 2. Gemini TA2 experiments are not covered in the scope of this report. It is also worth noting that there is often significant variation in target numbers across each campaign; gas jet experiments for example may only request a few tens of targets such as alignment wires or filter packs whereas other experiments may request thousands of array or tape-based targets.

Table 2: Experimental campaigns supported by the Target Fabrication group and the types of targets requested over the 2023/24 operating period.

Experiment	Area	Main target types
0523 Kettle (22210012)	Gemini TA3	Multi-layer tapes, filter packs
0823 Jaroszynski (22210025)	Gemini TA3	Gas jet, alignment
1023 Doria (22210024)	Gemini TA3	Ultra-thin foil—arrays
0224 Sarri (23210006)	Gemini TA3	Gas jet, alignment
0324 Najmudin (23210013)	Gemini TA3	Gas cells
0523 McKenna (22210005)	Vulcan TAP	Ultra-thin foils—single posts
0523 Oliver (22210011)	Vulcan TAW	Thick foils—single posts, 3D microstructures, alignment
0623 Woolsey (22210003)	Vulcan TAW	Thick foils—single posts, filter packs
0623 Keenan	External: AWE	Thick foils—single posts, gas cells
0823 Fuchs (22210006)	Vulcan TAW	Thick foils—single posts
0224 Lancaster	Vulcan Dark Period: Michigan	Thick foils—arrays
1123 Ahmed	Vulcan Dark Period: ELI-NP	Ultra-thin foil—arrays

Target Complexity and Classification

Targets are classified as Class 1, Class 2 and Class 3, depending on their level of complexity or the level of research and planning required for their manufacture. While the definitions can be somewhat subjective, they are generally defined as follows:

- Class 1: require fewer specialist resources to manufacture. Materials are typically procured 'off-the-shelf' and minimal specialist equipment is required for assembly. Typical targets include several-micron-thick foils or alignment wires glued to posts.
- Class 2: require the use of specialist manufacturing equipment and knowledge, which would be a very involved process for a non-Target Fabrication specialist to replicate. Examples include multi-nanometre thin-films and multilayer coatings.
- Class 3: require long-term R&D projects to establish and perfect, often referred to as "high-specification targets". Such targets include complex 3D assemblies, MEMS-components, low-density foams and multi-step/ etched tape targets. If the complexity of a Class 3 target derives from the development of an initial process or building/procuring specialist apparatus, then it may be downgraded from a Class 3 for subsequent experiments (such as multi-layer tape targets).

It is important to note that for the scope of this report there is a distinction between a "target" and a "component". A component is any single item that is fabricated and issued for experimental delivery from the laboratory, which can include components with multiple individual targets on it. Thus, an array is a single component, which typically holds 25 targets. Similarly, a spool of tape is considered a single component, which contains many hundreds of targets per spool.

Target Supply

Over the 12 experiments supported over the 2023/24 operating period, a total of 7887 targets were issued.

79.8% (6291) of these targets were supplied to Vulcan-based experiments, and the remaining 20.2% (1596) were supplied to Gemini. Although Gemini is a higher repetition rate laser and typically commands larger target quantities compared to Vulcan, there are two reasons leading to this year's supply inversion:

- During this operating period there were a high number of gas jet/refillable gas cell shots on Gemini, which are not tracked for the scope of this report.
- Of the 6291 targets supplied to Vulcan-based experiments, 1241 targets were supplied to Vulcan TAW and TAP—the remaining 5050 were supplied to Dark Period supporting facilities, which were able to shoot array-based targets.

Figures 6 and 7 below shows the complexity breakdown of targets delivered to both Gemini and Vulcan-based experiments over the 2023/24 operating period.

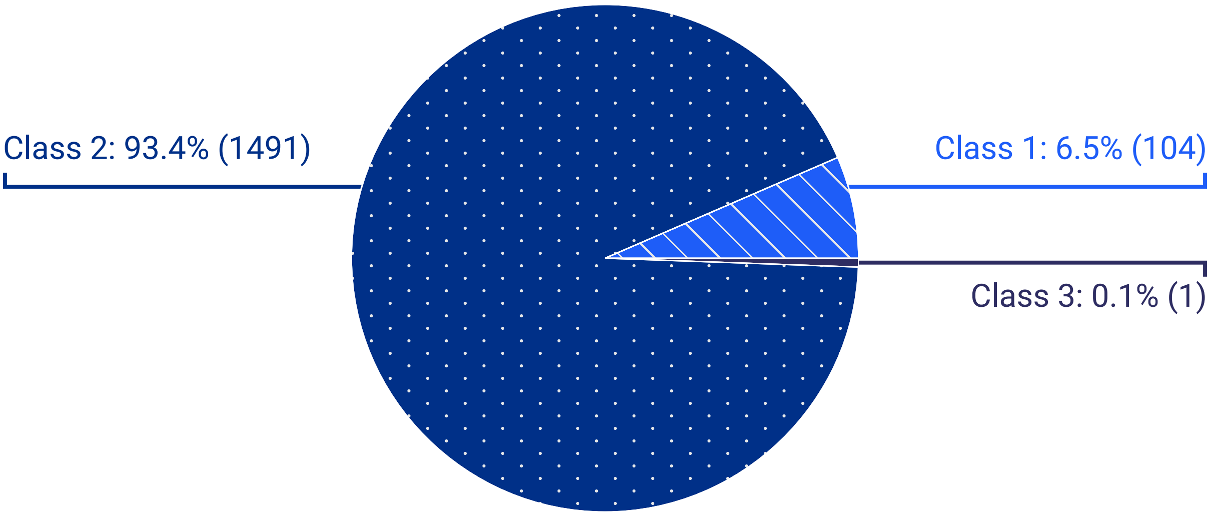

Figure 6: Target complexity breakdown (Class 1, 2 and 3 targets) delivered to Gemini experiments in 2023/24.

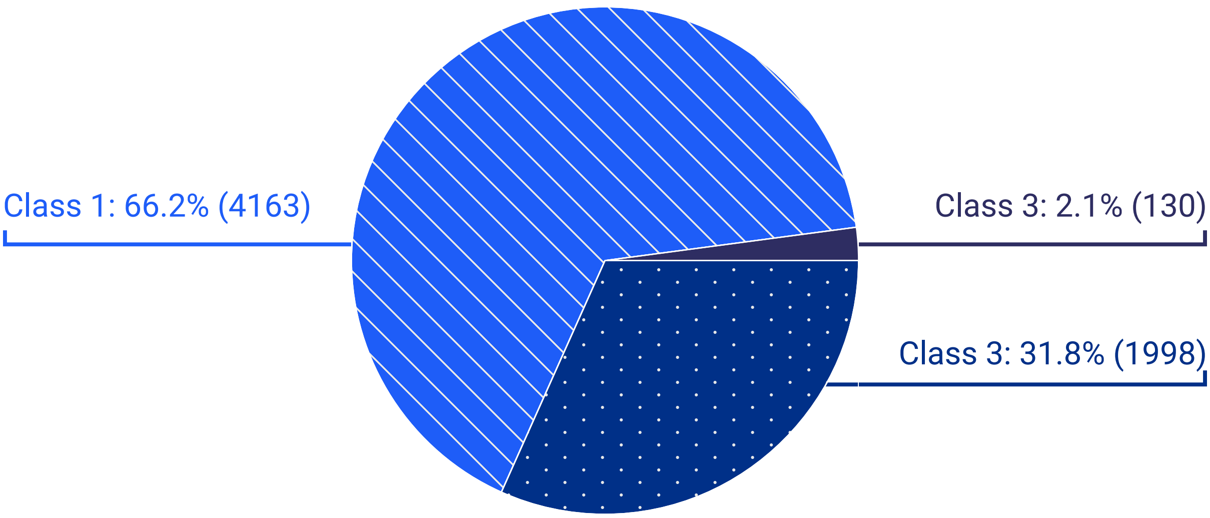

Figure 7: Target complexity breakdown (Class 1, 2 and 3 targets) delivered to Vulcan-based experiments in 2023/24.

Comparing Figures 6 and 7 shows that while Vulcan experiments generally requested a much higher percentage of simpler Class 1 targets, it also commanded a much higher (130 vs 1) quantity of the highest complexity of targets. This is due to the fact that as Vulcan operates on a lower repetition rate, and typically with only a few targets mounted in a single pumpdown cycle, precise alignment is crucial and thus a larger proportion of alignment (i.e. Class 1 targets) are necessary.

Gemini experiment requirements over the operating period comprised mainly of multi-layer tapes or ultra-thin foil arrays, and thus the vast majority of target requests are classified as Class 2 complexity. The fact that a much larger quantity of targets (i.e. in tape or array form) can be installed in a single pumpdown cycle means that a lower proportion of alignment targets are required.

Table 3: A detailed breakdown of target types supplied to each facility over the reporting period.

Target Type	Gemini	Vulcan-based
Alignment	16	156
Thick foils	88	4007
Ultra-thin foils	571	1993
Multi-layer foils	920	5
3D micro-structures	1	130
Foams	0	0
MEMS/Mass limited	0	0
Total	**1596**	**6291**

Target Supply Trends

Over the last 13 years (over which detailed target records have been tracked), there has been a steady, year-over-year increase on the number of targets requested. With the exception of 2021/22, which had no Gemini TA3 solid target experiments, there has been a significant increase in target supply over the last five years--especially evident between 2022 and 2024. This is driven by the development of both tape targetry technology and also the TAAS automated assembly robotic system[2] within Target Fabrication, enabling much larger quantities of targets to be manufactured.

Figure 8 shows the total targets supplied in each operating period since 2011-2012.

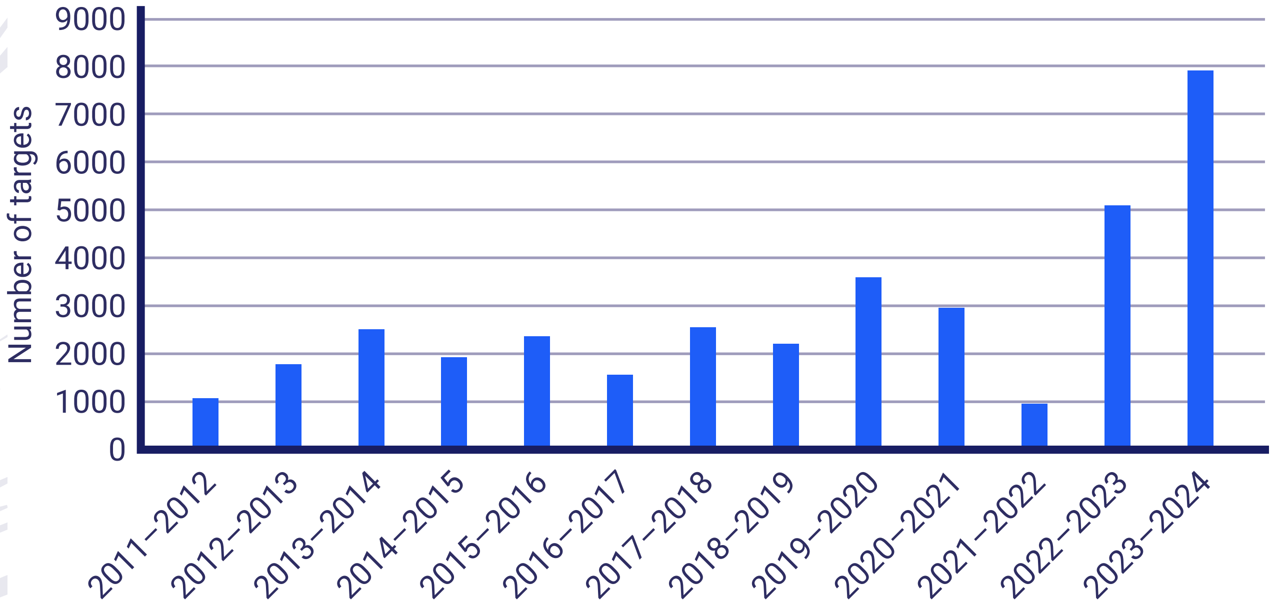

Figure 8: Total number of targets supplied to CLF HPL experiments over each operating period since 2011.

The number of targets supplied in a given year is dependent on experimental proposals, however, and depending on the target types necessary for each experiment this gives rise to fairly significant variability in target numbers year-on-year (e.g. gas jet vs arrays). The sharp supply increase over the last two years is expected to continue to rise, due to the commissioning of EPAC. As this is an applications-based facility, with 10 Hz repetition rate, it is likely that within the next few years solid target requests will be into the tens of thousands.

Quality Assurance

All materials, thin-film coatings, assembly components and characterisation for targets that are issued for HPL experiments are tracked wherever possible. This ensures there is traceability for any target defects if an anomalous result from the dataset following interaction is discovered. Although not currently certified to the ISO9001 QA standard, many of its processes are followed.

Some of the metrics that are tracked are target returns and modifications. This shows how many targets are: a) issued although not requested officially during the planning cycle of the experiment; b) modified during the course of an experiment; and c) returned during/after the experiment due to being out of specification or unable to be shot.

Figure 9: Total issued targets compared to the targets returned unshot or out of specification.

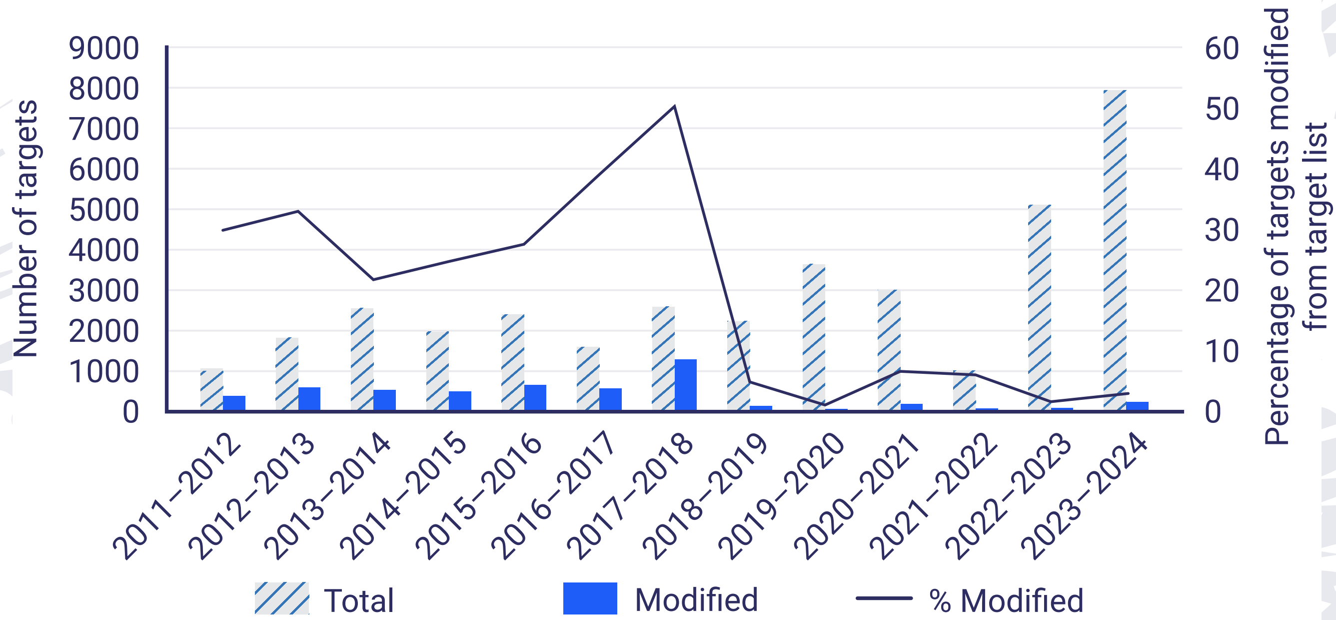

Figure 10: Total issued targets vs those that deviated from their signed-off specification in the planning cycle of the experiment.

As can be seen in Figure 9, the percentage of returned targets has significantly fallen over the last year–the primary reason for this is that a large proportion of the year's targets were issued to off-site experiments to support the Vulcan Dark Period, making target return very difficult or impossible in the scope of a limited time experiment. Further, due to the time-expense of manufacture of tape targets, and the fact that a single spool of tape contains several hundred targets, these are often not returned, somewhat skewing this metric.

Figure 10 shows the number of targets that did not match the specification that was signed off during the experimental planning cycle. Target requests are typically signed off 6–8 weeks prior to the beginning of the experiment, but Target Fabrication try to accommodate day-to-day changes in target design as the scientific aims of the experiment evolve. This is a significant benefit of having an in-house target fabrication capability. The decrease in modified target numbers is for a similar reason to that for target returns; as target requests become either more complex or there is an increase in shot numbers, sign-off has to be more absolute.

Future Targetry Supply

In collaboration with Queen's University Belfast and SLAC, the Target Fabrication group is developing a liquid targetry system capable of injecting nanometre-thick sheets of de-ionised water in vacuo, for both future Gemini experiments as well as a plasma mirror and potential ion acceleration source for EPAC EA2. The first experiment using this system is scheduled for July 2025.

The group continues to develop ultra-stable tape drive systems[3] as well improving the method for fabrication of multi-layered complex tape targets on spools. A Reel-to-Reel system, allowing a two order of magnitude increase in tape target manufacture, is due for commissioning in 2025 and will integrate the Target Fabrication group's extensive knowledge and in-house technologies to further advance its capability in this field for EPAC delivery.

External Contracts

In the reporting period 2023/24, the operations of Scitech Precision Limited (SPL), the target fabrication commercial spin out, supported the user community on external facilities and continued to expand its capabilities in high repetition rate target manufacture with the delivery of tape drive systems to high power laser facilities around the world. The expansion of the user community across Europe and in the US drove sales of targets to a wider array of customers.

A total of 33 (slightly down from 36 in 2022/23) institutions engaged with SPL over this period for 113 individual contracts (down from 115 last year). However, the turnover increased to a record value of £407k, which is a 35% increase and represents a change in focus of the business from small value contracts to larger value national laboratory lab support, particularly in the US. In the reporting period, SPL delivered contracts where it utilised the wide range of capabilities that are available on the RAL campus, including the combination of single point diamond turning and micro-assembly to deliver highly complex targets as well as the delivery of complete targetry systems to complement its capabilities in individual target supply. This work is underpinned by the licensing agreements SPL has with STFC to market and sell the tape drive technology, delivering royalties into the CLF and to its inventors.

Acknowledgements

The Target Fabrication group would like to thank Dr Charlotte Palmer and Peter Parsons (Queen's University Belfast), as well as Griffin Glenn and Daniel DePonte (SLAC) for their continued collaborative efforts in the design of the CLF's liquid targetry capability.

References:

1. S. Astbury, C. Spindloe & M. Tolley "Target Fabrication Operational Statistics April 2022–2023", CLF Annual Report 2022–2023
2. J. Fields, P. Ariyathilaka, S. Astbury, C. Spindloe & M. Tolley "Current developments in the Target Array Assembly System", CLF Annual Report 2022–2023
3. W. Robins, S. Astbury, C. Spindloe & M. Tolley "Advances in Tape Target Technologies towards 1Hz Operation for EPAC and other High Repetition Rate Facilities", CLF Annual Report 2021–2022

Authors: S. Astbury ✉, C. Spindloe and M.K. Tolley

Vulcan

Vulcan has completed its final experimental period (April to September 2023) ahead of the Vulcan 20-20 upgrade, with 37 full experimental weeks allocated between target areas West (TAW) and Petawatt (TAP). Overall, the laser statistics show an operational standard consistent with that achieved last year, with an overall reliability percentage of 92%.

The experiments dependent on the long pulses continued to present less than 5% rms values, resulting in a reliability of 99% for the M Oliver experiment. The short pulse beamlines had a lower than expected reliability for the Woolsey experiment, due to alignment sensitivity issues. On all other experiments, reliability was above the 92% baseline.

Table 5 (next page) shows the operational schedule and statistics for 2023/24. Information on the number of shots, energy-on-target success rate and availability hours is also provided in the table. 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 were fired to target this year was 860. Table 4 shows how this figure compares with that for the four previous years. 69 shots failed to meet user requirements. The overall shot success rate to target for the year is 92%, compared to 84%, 80%, 88% and 92% in the previous four years.

Table 4: Shot totals and proportion of failed shots for the past five years.

Year	Total number of shots	Number of failed shots	Reliability
2019–2020	653	102	84%
2020–2021	325	64	80%
2021–2022	604	73	88%
2022–2023	601	51	92%
2023–2024	860	69	92%

Table 5: Experimental schedule for the period April to September 2023.

Period	TAW	TAP
6 March – 15 April	**C Armstrong** Direct Laser Acceleration of Electrons to Superponderomotive Energies (Shots 72, Failed 4, Reliability 94.4%) (Availability 83.8%, w extra hours 91.3%) (5 + 1 weeks) 22110016	N/A
13 March – 15 April	N/A	**M Borghesi** Ultra-high dose rate effects in cellular response to proton irradiation (Shots 122, Failed 9, Reliability 92.6%) (Availability 75.9%, w extra hours 88.0%) (5 weeks) 22210020
1 May – 3 June	**M Oliver** Direct Imaging of the Inelastic Response of Silicon to Shock Compression (Shots 102, Failed 1, Reliability 99.0%) (Availability 89.4%, w extra hours 97.8%) (5 weeks) 22210011	**P McKenna** Non-linear Compton scattering from intense laser pulse interactions with near-critical-density plasma (Shots 88, Failed 4, Reliability 95.5%) (Availability 90.6%, w extra hours 99.0%) (5 weeks) 22210005
26 June – 29 July	**N Woolsey** Characterisation of stimulated Raman sidescattering and its competition with backscattering in the context of Direct Drive Laser Fusion (Shots 141, Failed 28, Reliability 80.1%) (Availability 90.3%, w extra hours 109.0%) (5 weeks) 22210003	N/A
3 July – 13 August	N/A	**Commercial Beam Time** (Shots 208, Failed 15, Reliability 92.8%) (Availability 88.8%, w extra hours 94.4%) (6 weeks) 23510000
21 August – 23 September	**J Fuchs** Investigating particle acceleration dynamics in interpenetrating magnetized collisionless super-critical shocks (Shots 125, Failed 8, Reliability 93.6%) (Availability 97.6%, w extra hours 107.2%) (5 weeks) 22210006	N/A

Figure 11 shows the reliability of the Vulcan laser to all target areas over the past five years. The shot reliability in 2023/24 to TAW was 91.8%, down 1.2% from the previous year. The shot reliability to TAP was 93.6%, up 7.6% from 86% in 2022/23.

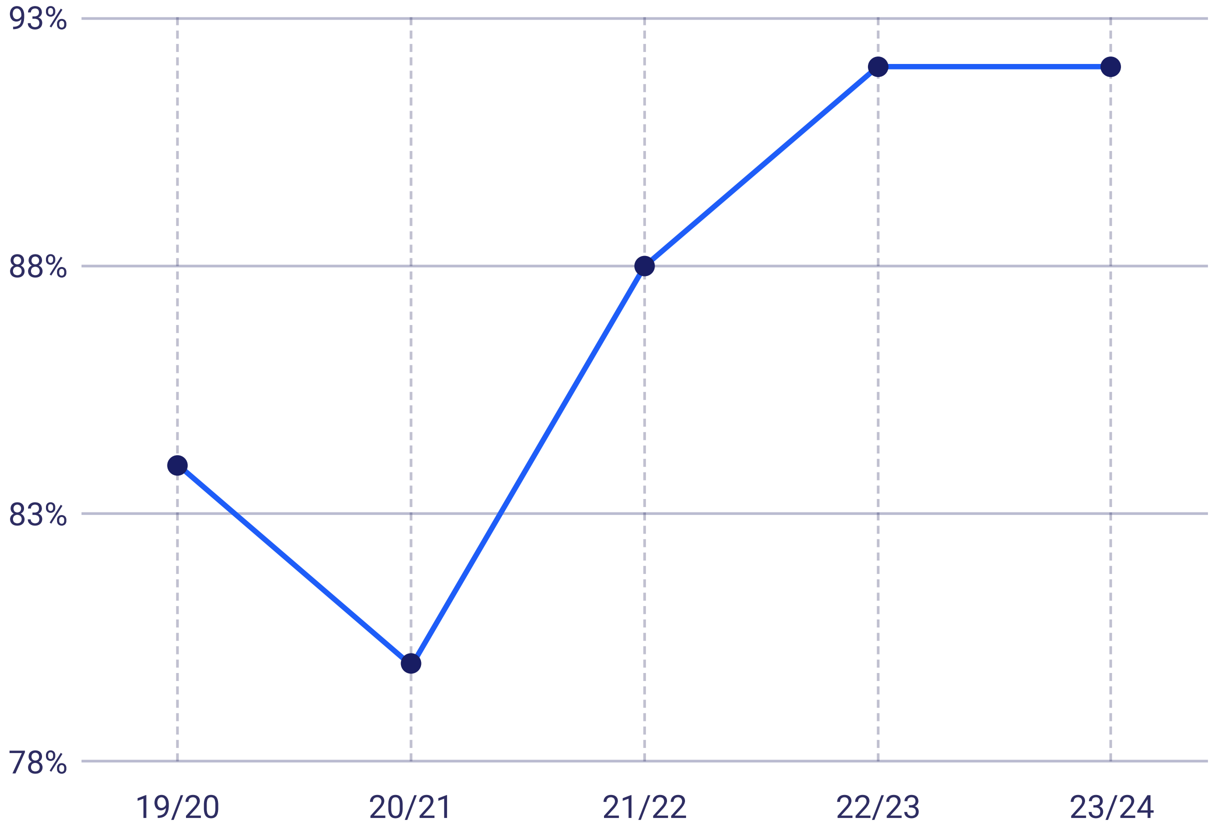

Figure 11: All areas shot reliability for each year 2019 to 2023.

Availability was affected by a single event for Woolsey and commercial access campaigns that took two days out of the operational campaigns.

Availability was reduced by problems with the high voltage part of the system, in rod or disk amplifier elements. Throughout the year, there were 11 failures on elements on the disk amplification chain/capacitor bank, and two on the rod amplification chain. Each time there was a problem with these elements, it took between three hours and one-and-a-half days to resolve.

There is a requirement (originally instigated for the EPSRC FAA) that the laser system be available from 09:00 to 17:00 hours, Monday to Thursday, and from 09:00 to 16:00 hours on Fridays, during the five-week periods of experimental data collection (a total of 195 hours over the five-week experimental period). The laser has mainly 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 88% of the time during contracted hours, compared with 95.7% for the previous year. The overall availability to all target areas was over 98%%, compared with 113.2% in 2022/23, with an average reliability of 92.6%.

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