# Artemis Operations Report

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## Introduction

This was the first year of Artemis returning to operations, although the effects of the COVID pandemic meant that the upgrade project was continuing in parallel.

The year started with alignment and testing of the high harmonic generation (HHG) beamline for the 1 kHz laser system. Changes made to the beamline during the upgrade project meant that the conditions for HHG had to be optimised for the new geometry. The mirror used for alignment after the monochromator was motorised, along with the pump-probe alignment mirror in the toroidal mirror chamber. The design changes, coupled with the replacement of the optics in the monochromator, improved the throughput of the beamline by a factor of ten.

The engineering work for the upgrade project was completed at the end of the summer, and the lab was officially opened by Professor John Collier, Director of the CLF, in September.

The first experiment of the year was a novel type of experiment for Artemis: molecular-frame photo-angular distributions. This was a challenging experiment that required the laser system to be running with high stability to get three beams on target.

The autumn provided the first opportunity to welcome back laser service engineers. This meant an extended period of both installing the new 100 kHz system, making it ready for site acceptance tests, as well as servicing the 1 kHz system to optimise its performance. The site acceptance tests were completed successfully at the end of November.

Three further experiments were carried out at the end of 2021, including a commissioning experiment using the AMO chamber to look at roaming dynamics in acetaldehyde, a materials experiment on the 1 kHz beamline, and a collaborative experiment with Ultra using the 100 kHz system for a Kerr Gated Raman proof-of-principle experiment. In the New Year, Artemis undertook another novel experiment, using the hollow fibre compressor for generating high harmonics in solids.

A safety shutdown followed, where improvements were made to the gas handling systems in the lab, along with some procedural changes. The year concluded with the 1 kHz lab open for user experiments, commissioning of the XUV beamline in the 100 kHz lab in preparation for upcoming materials science experiments, and the two laser systems running at specification.

*Table 1: Artemis operations by week in 2021/22.*

| Week beginning | Activity |
|---|---|
| 05/04/2021 | 1 kHz beamline installation and testing |
| 12/04/2021 | |
| 19/04/2021 | |
| 26/04/2021 | |
| 03/05/2021 | |
| 10/05/2021 | |
| 17/05/2021 | |
| 24/05/2021 | Thompson - 20120006 |
| 31/05/2021 | |
| 07/06/2021 | |
| 14/06/2021 | |
| 21/06/2021 | |
| 28/06/2021 | |
| 05/07/2021 | Laser Maintenance |
| 12/07/2021 | |
| 19/07/2021 | Thompson - 20120006 |
| 26/07/2021 | Interlock Upgrade |
| 02/08/2021 | |
| 09/08/2021 | |
| 16/08/2021 | Laser Maintenance |
| 23/08/2021 | |
| 30/08/2021 | Thompson - 20120006 |
| 06/09/2021 | |
| 13/09/2021 | Flatfield Spectrometer Installation |
| 20/09/2021 | Laser Install & Servicing |
| 27/09/2021 | |
| 04/10/2021 | |
| 11/10/2021 | |
| 18/10/2021 | |
| 25/10/2021 | |
| 01/11/2021 | Da Como - 20120002 |
| 08/11/2021 | |
| 15/11/2021 | |
| 22/11/2021 | Laser Site Acceptance Tests |
| 29/11/2021 | Laser Site Acceptance Tests / AMO Commissioning |
| 06/12/2021 | AMO Commissioning |
| 13/12/2021 | |
| 20/12/2021 | Maintenance Week |
| 27/12/2021 | Christmas Shutdown |
| 03/01/2022 | Maintenance Week |
| 10/01/2022 | Laser Service |
| 17/01/2022 | Matthews - 20120009 |
| 24/01/2022 | |
| 31/01/2022 | |
| 07/02/2022 | Safety System Upgrades |
| 14/02/2022 | |
| 21/02/2022 | |
| 28/02/2022 | |
| 07/03/2022 | |
| 14/03/2022 | |
| 21/03/2022 | Chamber Changeover and setup |
| 28/03/2022 | |

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# Gemini Operational Statistics

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During the reporting year, April 21 – April 22, a total of six complete experiments were delivered in the Astra-Gemini Target Area and three experiments in TA2. In total 33 high power laser experimental weeks were delivered to the Gemini Target Area and 23 weeks to TA2. The delivered Gemini schedule is presented in Figure 1.

The availability of the Gemini laser system (delivery to the Gemini Target Area) was 82% during normal working hours, rising to 146% with time made up from running outside of normal working hours. The reliability of the Gemini laser was 88%. An individual breakdown of the availability and reliability for these TA3 experiments conducted is presented in Figure 2.

TA2 availability was 89% during normal working hours, rising to 125% with time made up outside of normal working hours. The reliability of the laser delivery to TA2 was 92%. An individual breakdown of the availability and reliability for these TA2 experiments conducted is presented in Figure 3.

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.

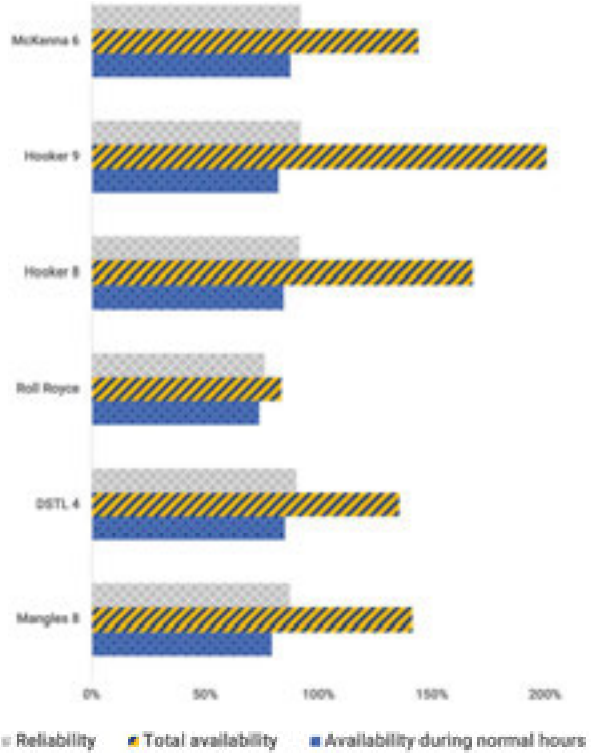


*Figure 2: Gemini TA3 2021/22 operational statistics.*

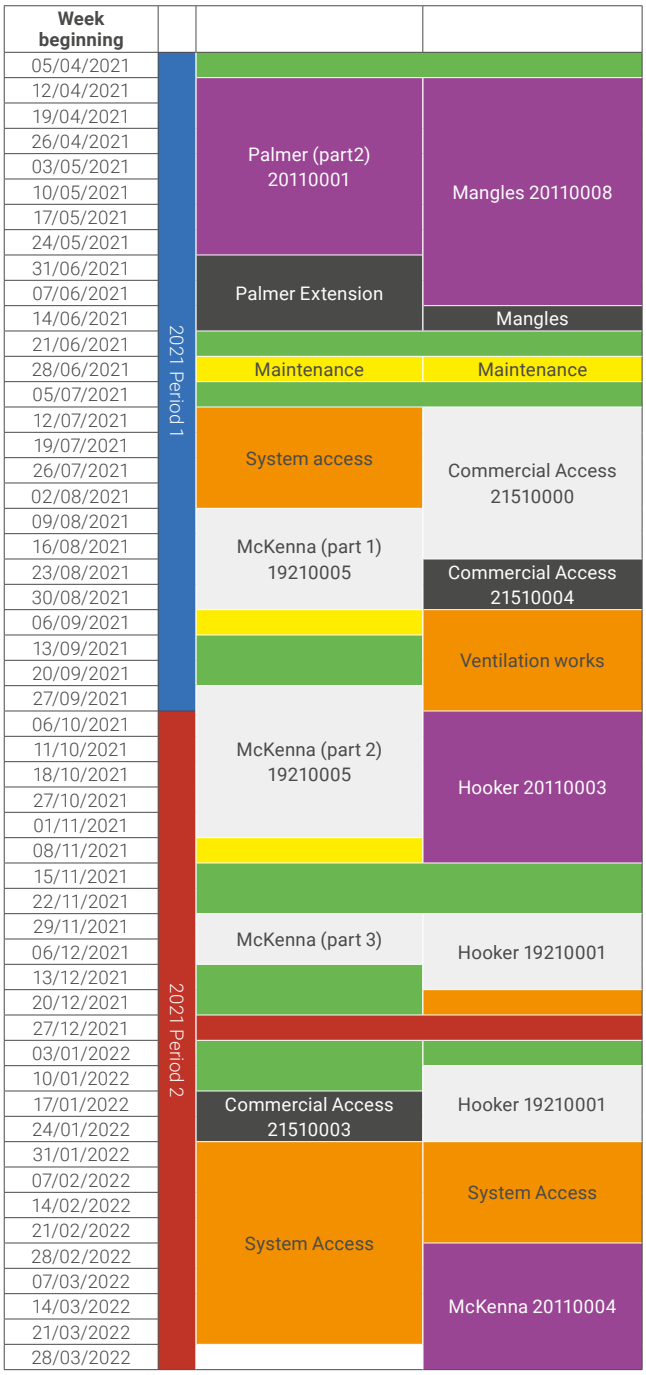


*Figure 1: Gemini 2021/22 operational schedule.*

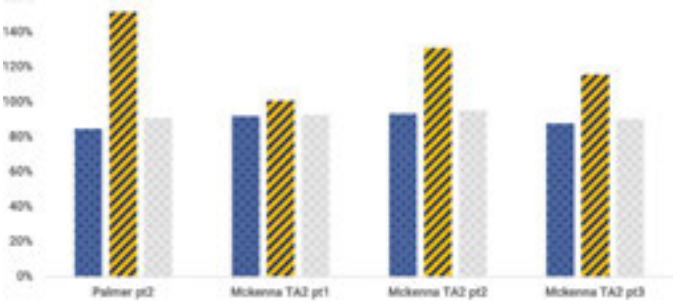


*Figure 3: 2021/22 TA2 operational statistics.*

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# Octopus and Ultra Operational Statistics

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During the reporting period (April 2021 to March 2022), there were not any calls for applications to access Octopus and Ultra facilities due to the uncertainty surrounding the global Coronavirus pandemic. The statistics reported on this page represent experiments awarded access time in previous calls for access but re-scheduled to take place during the reporting period.

## Octopus facility

17 unique User groups performed re-scheduled experiments at the Octopus facility during the reporting period. 21 experiments comprising 58 weeks of access time were delivered to the UK User community throughout the year. In addition, a total of five weeks proof of concept experiments and 2.4 weeks of commercial access were scheduled. Figure 1 shows that Biology and Bio-materials was the most popular experiment subject conducted.

There were a total of 14 formal reviewed publications recorded throughout the year.

## Ultra facility

11 unique User groups performed re-scheduled experiments at the Ultra facility during the reporting period. 12 experiments comprising 38 weeks of access time were delivered to the UK User community throughout the year. In addition, three days of proof-of-concept experiments and two weeks of commercial access were scheduled. Figure 2 shows that Chemistry was the most popular experiment subject conducted.

There were a total of 17 formal reviewed publications recorded throughout the year.

## Octopus and Ultra availability and user satisfaction feedback

A total of 27 hours downtime was reported over the combined 96 weeks of delivered access during this reporting period. Figure 3 shows an average user satisfaction rating of 93.4% over the five surveyed categories.

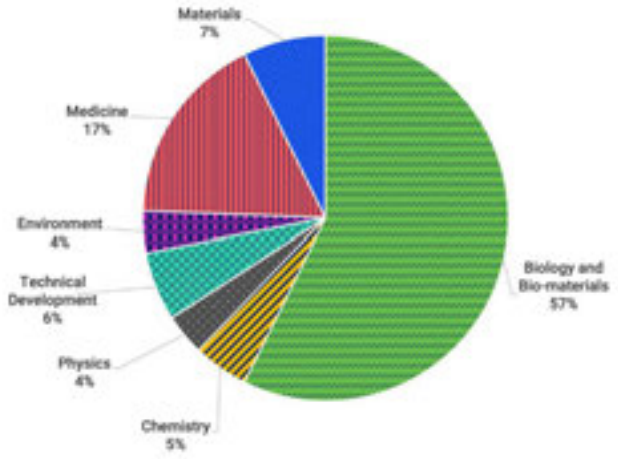


*Figure 1: Octopus experiments by subject.*

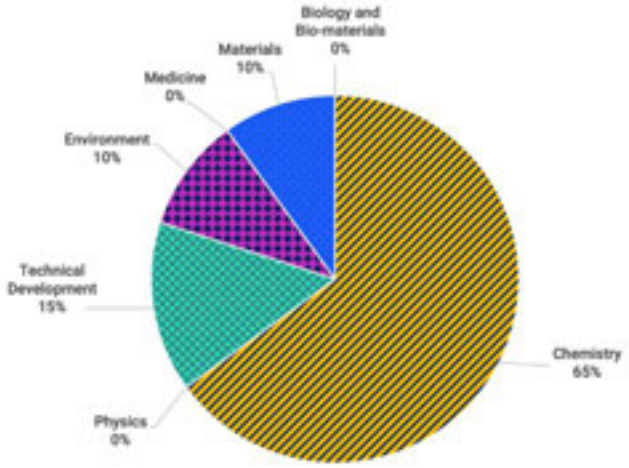


*Figure 2: Ultra experiments by subject.*

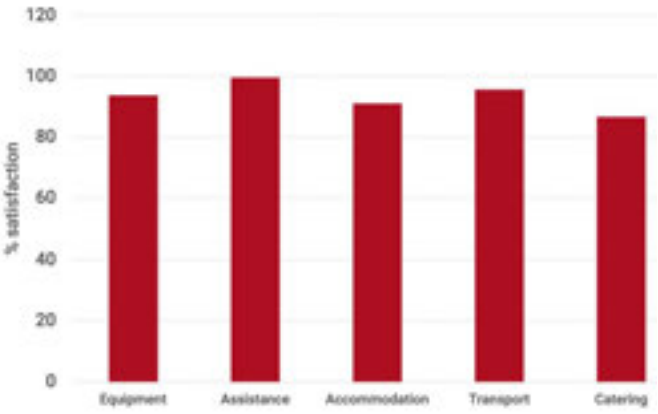


*Figure 3: Octopus and Ultra average user satisfaction.*

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# Target Fabrication Operational Statistics

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## Introduction

The following report details the operational statistics for the Target Fabrication Group of the Central Laser Facility (CLF) over the reporting period of April 2021 – April 2022. Target supply to the four high-power laser (HPL) experimental areas in the CLF is covered (Gemini TA2, TA3 and Vulcan TAP, TAW).

Over the reporting period a total of 11 HPL experiments were supported, six in Vulcan and five in Gemini. In comparison to the previous reporting period (January 2020 to April 2021), the number of experiment-weeks that the Target Fabrication Group supported was 210% higher (82 weeks compared with 38 weeks in 2020-2021). This increase was primarily due to the removal of restrictions imposed by the government in response to the SARS-CoV-2 pandemic and the return to normal user operations that this allowed. Support is back to the level that was seen in 2018-2019.

The vast majority of the targets captured in this report were used for laser-matter interactions; however, some targets (for example filter packs) are used for diagnostic purposes and often returned post-experiment. Over the last few years, the development of the CLF tape drive systems [1,2] has facilitated the delivery of large numbers of high-repetition rate (HRR) targets, as well as acting as a beam diversion system for imaging experiments. Thus far, the tape drive system has only been employed on the Gemini facility and while the target delivery figures for these areas seem low, it is typical that an entire spool of tape will be captured as a single target on the issue list. Cross-referencing with the eCAT shot data for every experiment in each target area would be necessary to get a true value of target shots on this media. While this is a considerable endeavour to carry out for every experiment that uses HRR media for this report, this data is captured in the section 'High-Repetition Rate Targetry' at the end of this paper. This data skews the reporting numbers and, in the future, for EPAC, the Group will likely have to report on effort/time rather than shot numbers.

## Supported Experiments

As documented in previous statistical reports, each target design varies in complexity depending on the area of physics it is designed to investigate, and thus differs from area to area and in some cases shot to shot. Vulcan experiments are typically set up in a single-target shot mode and so tend to comprise single targets on stalks, possibly as part of a cluster of experimental packages and backlighters, and are often more complex in design. Targets for Gemini experiments are more HRR-focused and usually comprise simple foil arrays mounted on a target wheel or, more recently, tape-drive. Many Gemini experiments are gas target led and although the group does not facilitate gas targets directly (they are an engineering group led component), we are involved in characterisation and advanced machining if required.

Table 1 details the supported experiments over the reporting period and their duration, including extension weeks. It is worth noting that two extensive TA2 experiments are covered in this report, which differs from previous years, totalling 23 support weeks, although the level of required support for TA2 experiments from the Target Fabrication Group is usually limited.

*Table 1: Experiments supported by the Target Fabrication Group through the 2021/22 reporting period.*

| Proposal Number | Date/Area/PI | Supported Weeks |
|---|---|---|
| 20110008 | 0421 GTA3 Mangles | 9 |
| 20110001 | 0521 GTA2 Palmer | 12 |
| 21510000 | 0721 GTA3 DSTL | 7 |
| 19210005 | 0821 GTA2 Pirozkhov | 11 |
| 20110003/ 19210001 | 1021 GTA3 Hooker | 8 |
| 19210010 | 0421 TAP McKenna | 6 |
| 20110006 | 0421 TAW Armstrong | |
| 18210011 | 0721 TAP Hicks | 6 |
| 21210001 | 1021 TAW Ridgers | 5 |
| 21210003 | 0122 TAW Norreys | 5 |
| 21210004 | 0322 TAW Kar | 5 |
| **Total** | | **82** |

## Target Complexity and Classification

The varying target types provided by the Target Fabrication Group are categorised as Class 1, 2 and 3 targets, and this offers a method of classifying the complexity and research/planning necessary for experimental delivery. These definitions are somewhat subjective in nature, but are typically classified as follows:

- Class 1: Targets that require fewer specialist resources to manufacture. Materials are typically procured 'off-the-shelf' and minimal specialist equipment is required for assembly. Typical targets include micron-thick foils or alignment wires glued to posts.
- Class 2: Targets that require the use of specialist manufacturing equipment and knowledge, which would be a very involved process for a non-Target Fabrication entity to replicate. Examples include nanometre thin-film and multilayer coatings.
- Class 3: Targets that require long-term R&D projects to establish and perfect, often referred to as "high-specification targets". Such targets include complex 3D assemblies, MEMS-coatings, reduced-density/ foams and multi-step tape targets.

## Target Supply

(Note – not including individual tape target shots, where one target can be 1000s of shots)

The 2021-22 supporting period saw a total of 982 targets supplied to the 11 experiments in the CLF, 93% of which to the Vulcan target areas and the remaining 7% to the Gemini areas. There are a few caveats here however in that typically an entire target array (common for Gemini experiments) with anything between 9 and 60 shots worth of targets is captured as a single target in the records register.

Figure 1 right shows the breakdown of target complexity by target area over the 2021-22 reporting period, excluding Gemini TA2 data, which will be discussed later in this report.

It can be seen that, on average, 25-30% of all targets are Class 2 or 3, which require significant development and research time to complete.

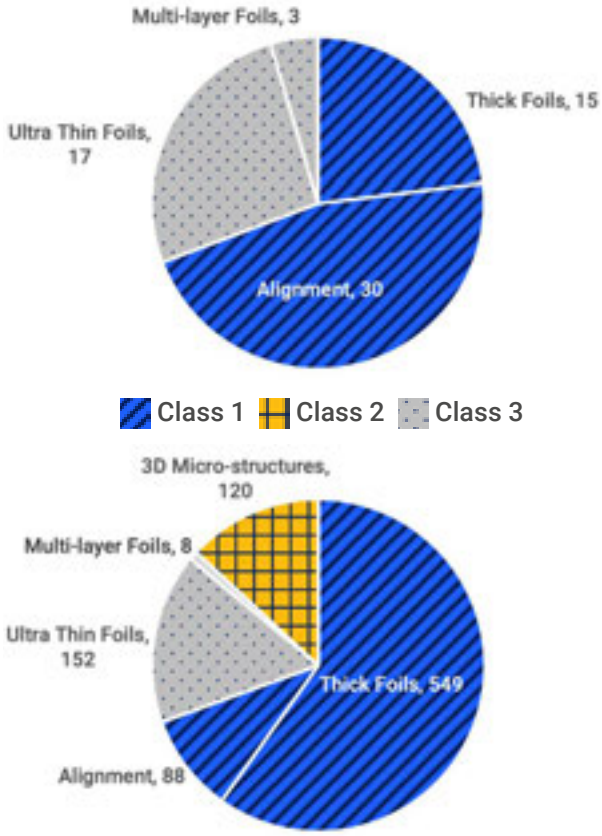


*Figure 1: A breakdown of target number and classification in the Gemini (above) and Vulcan (below) target areas over the 2021/22 reporting period.*

## Target Supply Trends

The Target Fabrication Group keep a record of all targets which have been issued to each experiment in the CLF for referencing and QA purposes and as such are wishing to reinstate ISO9001 quality management system which will be especially important when shot numbers inevitably increase when EPAC is in full operation in the coming years.

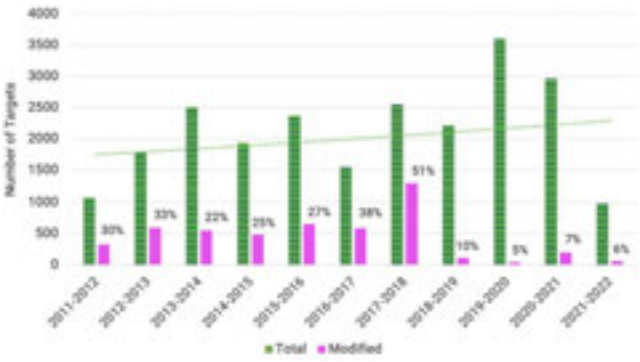


*Figure 2: Total targets delivered by reporting periods from 2011 onwards showing the percentage of targets that had to be modified from the initial request.*

Figure 2 shows the trend of target delivery over the past 11 reporting periods. This seems to indicate that there has been a significant reduction in target supply over the last year, with a total of 982, compared to 2959 targets supplied in the 2020-2021 period. However, this total omits those that comprised tape targets, highlighted later in this report. In the two previous reporting periods, complex tape targets were counted as individual shots and therefore the numbers are approximately 1500 higher than would have been reported if the tape were taken as a single target (as in this year's case).

Also shown in Figure 2 is the percentage of targets requested that were not on the target list initially requested by the user groups during an experiment. This typically means that the experimental aim during the campaign was re-aligned, or the on-shot data did not agree with the data from the simulations and the target requests were adjusted mid-experiment to achieve the physics results. This demonstrates the key benefit to the users of having an embedded target fabrication facility on site, where technicians can quickly adapt to a change in demand. There has been a significant improvement in reducing this figure over the past few years, which could be attributed to: better simulations and modelling; an increase in target complexity (and thus lack of adaptability mid-experiment); or the experience of the user groups. In total over the 2021-22 operating period, 60 of the 982 targets supplied were modified.

Figure 3 below shows the number of targets which were returned due to being out of specification or surplus to requirements over the reporting periods from 2011-22.

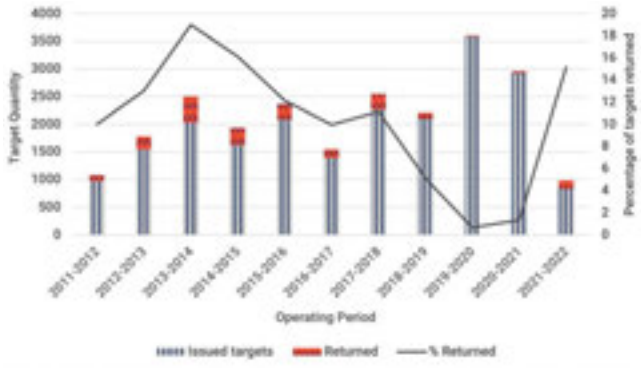


*Figure 3: Returned targets vs total targets supplied over the last eleven reporting periods.*

As can be seen in Figure 3, a more targets were returned than in the previous few years of experiments. This increase is attributed to the increase in targets delivered to the Vulcan facility which are more complex in nature, as well as the fact that there were comparatively fewer Gemini targets recorded for reasons previously discussed. The HRR nature of Gemini target areas tends to lead to fewer target returns causing a significant skew to the returns figures by area.

## High-Repetition Rate Targetry

The Target Fabrication Group has been developing a tape driven target capability over the past few years, which has started to see some use in experimental campaigns in Gemini GTA2 and GTA3 [1,2]. While the Target Fabrication Group does have the technology available to produce multi-layer tape targets, the experiments that used tape targets during 2021-22 comprised simple off-the-shelf tapes and have been captured separately so as to not significantly skew the data. Figure 4 below shows the target output including simple tape media.

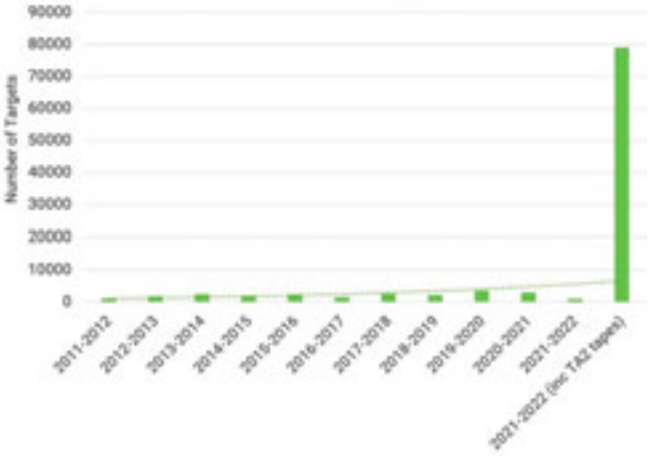


*Figure 4: Total targets supplied to each area, including shots on tape media in GTA2 experiments.*

As visible in Figure 4, including shots on simple tape media, a total of 79,064 targets were delivered across the CLF in the 2021-22 period. As EPAC will ultimately operate at a similar repetition rate to TA2, this provides a useful metric as to how many targets can be expected on a single experiment (the vast contribution of tape shots came from the 0521 GTA2 Palmer campaign on polyimide, stainless steel and copper).

It is likely that, due to the expected significant rise in target demand, data on HRR systems will be captured separately to that for lower repetition, more complex target types. This data will include tapes and shots on liquid target systems, a further capability which the Target Fabrication Group are developing.

## External Contracts

In the reporting period 2021-2022 the operations of Scitech Precision Limited (SPL), Target Fabrication Group's commercial spin out to support the user community on external facilities, recovered for reasons the same as noted above that led to the increase in support for the CLF. The COVID-19 pandemic relaxation allowed many more user facilities to open and start experiments and therefore target requests increased. A total of 32 institutions engaged with SPL over this period for 98 individual contracts to a total value of £267k, which is a significant increase in turnover from the previous COVID-affected years and back to a pre-COVID level. In the reporting period, SPL continued to upgrade its capabilities in laser machining and also developed capabilities to deliver high repetition rate targets by integrating CLF tape systems with its Excimer laser tool.

## Summary

Over the 2021-2022 reporting period, the Target Fabrication Group has delivered nearly 1000 targets of varying complexity to the CLF, spread across operational weeks in Vulcan and Gemini that totalled 82 weeks of user support. The majority of these targets were spread across Class 1 targets (approx. 70-75%) and Class 2 and 3 complex targets (approx. 25-30%). It is noted, however, that new target types, such as tape targets, are not now included in the total numbers: with these included, the shot numbers would have been nearly two orders of magnitude higher.

It is also noted that the target trends are moving towards large numbers of tape-produced or thin foil array targets for Gemini, and this trend will continue as EPAC-related experiments come online. The Group is investing significantly in development of technologies and capabilities to meet this demand.

*References*

1. *S. Astbury, W. Robins, C. Spindloe & M. Tolley, "Progression of a tape-drive targetry solution for high rep-rate HPL experiments within the CLF", CLF Annual Report 2018-2019*
2. *W. Robins, S. Astbury, C. Spindloe & M. Tolley, "Experimental Testing and Fielding of the CLF Precision Tape Drive in the Gemini Target Area", CLF Annual Report 2020-2021*

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# Vulcan Operational Statistics

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## Introduction

Vulcan has completed another active experimental year (April 2021 - March 2022), with 35 full experimental weeks allocated between Target Areas West (TAW) and Petawatt (TAP). Overall the laser statistics show an improved operational standard, with an overall reliability of 88%.

Table 1 shows the operational schedule and statistics for this period. Information on the number of shots, energy-on-target success rate and availability hours are also provided in the table.

| PERIOD | TAW | TAP |
|---|---|---|
| **2021** | | |
| 26 April – 11 Jun | | P McKenna<br>*Optimisation of a hybrid ion acceleration mechanism towards a stable, high-energy ion source*<br>(Shots 71, Failed 11, Reliability 84.5%)<br>(Availability 53.2%, w extra hours 92.9%)<br>(5 weeks + extra 1 week)<br>19210010 |
| 17 May – 09 Jul | C Armstrong<br>*Monoenergetic and micron-scale source size neutron beam generation*<br>(Shots 95, Failed 28, Reliability 70.5%)<br>(Availability 75.8%, w extra hours 148.0%)<br>(5 weeks + extra 3 weeks)<br>20110006 | |
| 05 Jul – 13 Aug | | G Hicks<br>*Ion acceleration from optically shaped gas-jets*<br>(Shots 70, Failed 8, Reliability 88.6%)<br>(Availability 77%, w extra hours 97.1%)<br>(5 weeks + extra 1 week)<br>18210011 |
| 01 Nov – 15 Dec | C Ridgers<br>*Observing kinetic effects on the Biermann battery*<br>(Shots 72, Failed 17, Reliability 76.4%)<br>(Availability 81.6%, w extra hours 119.4%)<br>(5 weeks)<br>21210001 | |
| **2022** | | |
| 17 Jan – 23 Feb | P Norreys<br>*Measuring the equation of state of CH foam using VISAR and SOP for low convergence ratio ICF capsule studies*<br>(Shots 86, Failed 3, Reliability 96.5%)<br>(Availability 87.9%, w extra hours 107.9%)<br>(5 weeks)<br>21210003 | |
| 03 Mar – 10 Apr | S Kar<br>*Ultra-short, beamed source of keV-MeV neutrons*<br>(Shots 210, Failed 6, Reliability 97.1%)<br>(Availability 88.1%, w extra hours 112.1%)<br>(5 weeks)<br>21210004 | |

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

*Table 1: Experimental schedule for the period April 2021 – March 2021.*

Some points to note are that TAW operations had to be interrupted for beam stability and defocus investigations between August and October. TAP saw similar disruption between August and March due to floor work and chamber installation.

In Table 1, the first set of numbers in parentheses indicates 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 shows the availability of the laser to target areas during normal operating hours, along with operations outside these hours.

The total number of full disc amplifier shots that have been fired to target this year is 604. Table 2 shows how this figure compares with that for the five previous years. 73 shots failed to meet user requirements. The overall shot success rate to target for the year is 88%, compared to 90%, 86%, 81%, 84% and 80% in the previous five years. Figure 1 shows the reliability of the Vulcan laser to all target areas over the past six years.

| Year | No of shots | Failed shots | Reliability |
|---|---|---|---|
| 16 – 17 | 948 | 93 | 90% |
| 17 – 18 | 934 | 132 | 86% |
| 18 – 19 | 607 | 113 | 81% |
| 19 – 20 | 653 | 102 | 84% |
| 20 – 21 | 325 | 64 | 80% |
| 21 – 22 | 604 | 73 | 88% |

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

Compared with 2020-21, the shot reliability to TAW is up 16% to 88%, while the shot reliability to TAP is down 7% to 87%.

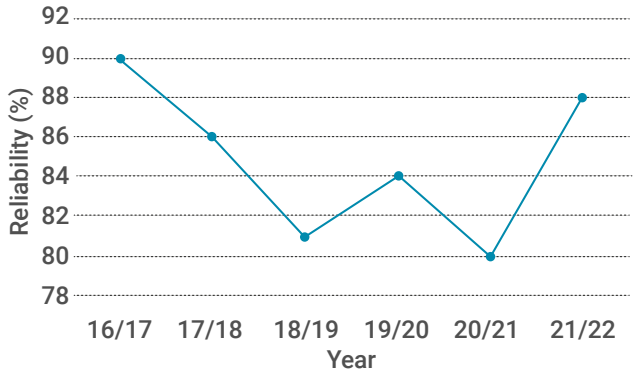


*Figure 1: All areas shot reliability for each year 2016/17 to 2021/22.*

Analysis of the failure modes reveals that the overriding causes of failed shots are beam alignment, high voltage related issues (especially its interference in the trigger system), and optical damage in the OPCPA system (TAP only). In order to mitigate the first two causes, several measures were implemented during the shutdown between the Armstrong and Ridgers experiments. The oscillator was moved in order to decrease the beam paths and get rid of the high voltage influence on the trigger system, and enclosures and imaging were introduced where possible. New diagnostics were added for the timing system and astigmatism correctors were introduced. These measures collectively resulted in an increase in the reliability of Vulcan TAW from 70.5% to 97.1%.

These modifications were carried out in conjunction with defocus evaluations, some of which will be published, and a realignment of the entire CPA system, stretchers and compressors. This work added to the time gap between the experiments.

There is a requirement which was 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 not always met the start-up 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 77.3% of the time during contracted hours, compared with 71.2% for the previous year. The overall availability to all target areas has decreased slightly to 112.9% compared with 124.1% in 2020-21. The time that the laser is unavailable to users is primarily the time taken for beam alignment at the start of the day.

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