Section 1
LASER SYSTEM REPORT

1.A GDL Facility Report

Throughout the first quarter of fiscal year 1984 (October through December 1983), GDL continued operations as a 351-nm interaction facility. Highlights of the quarter include a very successful campaign for the University of Pennsylvania (see the NLUF News) in the x-ray chamber, holographic experiments, characterization of the UV intensity distribution in the equivalent target plane, and a record number of damage test shots.

Through the latter part of the quarter, demand on GDL slackened, due to the demand for GDL experimental personnel in OMEGA experiments and demands on GDL operations personnel for "twenty-fifth beam" and Kuizenga oscillator integration projects (see the OMEGA Facility Report).

A summary of GDL operations follows:

Interaction Target Shots	59	(15%)
X-Ray Target Shots (Includes 39 NLUF shots)	61	(16%)
Damage Test Target Shots	219	(56%)
Pointing Shots	47	(12%)
Calibration Shots	2	(0.5%)
Miscellaneous Shots	2	(0.5%)
TOTAL	390	(100%)

ACKNOWLEDGMENT

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1.B OMEGA Facility Report

OMEGA systems operations during this quarter have consisted of acquiring all the necessary data for the successful performance review by DOE on 3 November, continuing to characterize the UV system performance, completing successful target shots for internal and NLUF experimental campaigns, and, finally, completing a series of shots aimed at optically cross-calibrating our 8″ Scientech calorimeters.

As the quarter began, we had completed a series of shots for preliminary data to be sent to DOE as a preview of our ability to meet the six-beam UV performance criteria. At the completion of this series, the system was shut down for substantial oscillator repairs, driver alignment, and crystal re-tuning. The shutdown took about two weeks and resulted in a higher, more reliable output power from the oscillator; a better-characterized, stable wavelength; and a better-aligned driver line, which led to significantly improved equivalent-target-plane intensity uniformity. By mid-October, we began firing the system for the completion of the DOE acceptance criteria, including characterization of the equivalent target plane; comparison of the UV output with *MIXER*[1] code predictions; characterization of beam transport; and measurements of pointing and centering accuracy, thermal transport, mass-ablation rate, and absorption. Summaries of the results of these measurements are found in articles appearing later in this volume.

As this experimental campaign ended in early November, further laser system characterization continued. In one series of target shots, we verified that no damaging IR radiation is propagated back through the laser system. Consistent measurements of less than 0.2 J propagating back into the driver line, with up to 70 J of UV (40 J of IR) on target, showed that 72-mm Pockels cells are not necessary as isolation devices for the system. The Pockels cells were therefore extracted from the system, resulting in a 10% increase in energy capability in the beams and possibly eliminating some phase problems noted in the equivalent-target-plane photographs.

By mid-November, target shooting resumed on a regular schedule averaging 12 target shots per day. A series of shots for the University of Maryland (NLUF) were completed, yielding novel XUV spectral data to be reported on elsewhere. Shot series were conducted for internal (LLE) programs studying electron thermal transport and coronal physics.

During the final week of operations in December, the 8″ Scientech calorimeters were optically cross-calibrated by means of accurate splitting of the laser beams into each of eight different calorimeters and by moving the calorimeters on each shot to eliminate beam-to-beam variations.

A summary of OMEGA system operations follows:

Target Shots (including 25 NLUF)	140	(39%)
Driver-Centering and Calibration Shots	92	(25%)
Crystal Tuning Shots	26	(7%)
Pointing Shots (including equivalent-target-plane characterization)	18	(5%)
Calorimetry Calibration Shots	41	(11%)
Miscellaneous (failures, software shots)	47	(13%)
TOTAL	364	(100%)

Throughout the first quarter of FY84, in addition to system operations, the operations group has been involved in manufacturing-engineering activities related to the upcoming conversion of at least six more OMEGA beams during this fiscal year. Further activities of the operations group include preliminary design work on the "twenty-fifth beam" project, where the GDL beam is to be synchronized with the OMEGA beams and pointed into the OMEGA target chamber as a backlight. Members of the operations group are on the task force for implementation of Kuizenga oscillators and pre-drivers into both GDL and OMEGA and are taking part in the design of various subsystems of the twenty-fifth beam, such as power-conditioning, active mirrors, safety interlock, synchronization, and alignment.

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1. R. S. Craxton, *Opt. Commun.* **34**, 474 (1980).

1.C OMEGA Wavelength Conversion

The conversion of six OMEGA beams to UV operation entailed decisions on issues such as:

(a) location of frequency-conversion cells,

(b) construction and alignment of frequency-conversion cells,

(c) pointing, focusing, and beam timing for UV beams, and

(d) beam-diagnostic systems.

In the subsections that follow, we discuss the resolution of these design issues of OMEGA and present the pertinent performance data that satisfy the DOE laser-system-performance criteria (see the IN BRIEF section). The construction, alignment, and successful performance of the frequency-conversion cells has been discussed previously in LLE Review.[1]

Frequency-Conversion-System Configuration

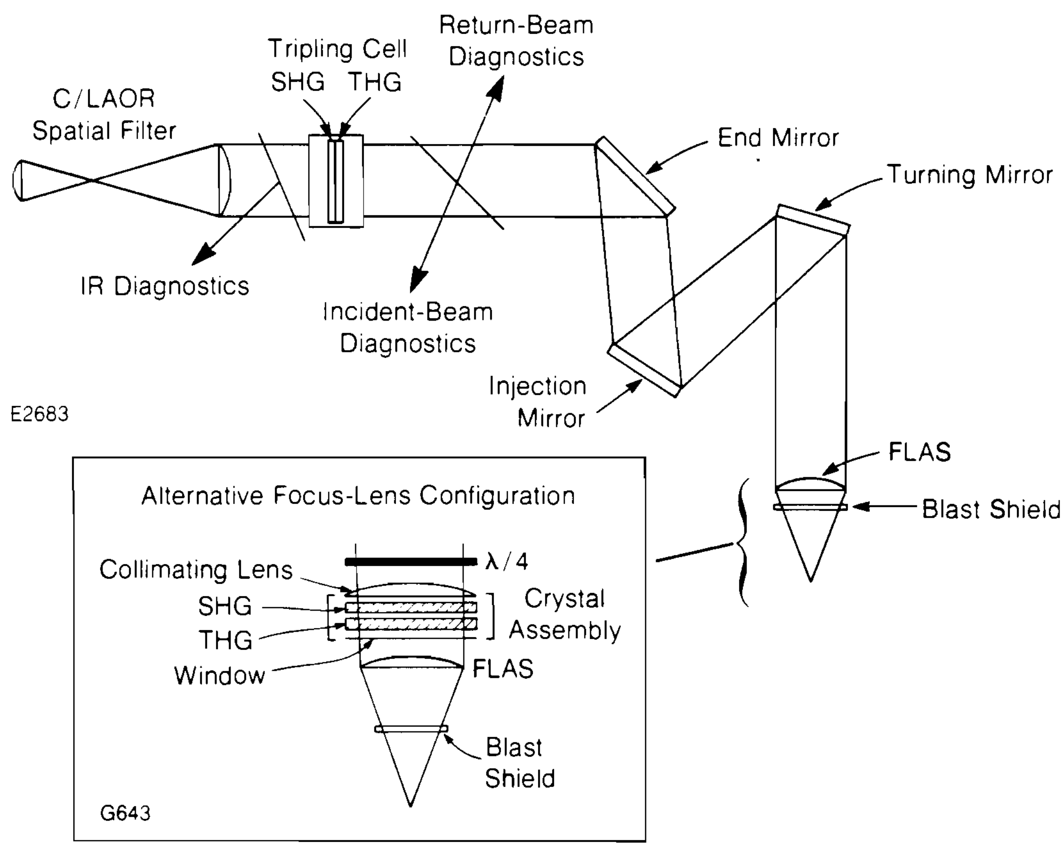
OMEGA is a 24-beam, Nd:glass laser system whose design and 1054-nm performance is discussed in Ref. 2. The OMEGA geometry (see Fig. 17.1) allows two basic locations for the conversion crystals: (a) at the focus lens and (b) at the output of the last spatial filter (C/LAOR). C refers to the final, 90-mm rod amplifier of the laser system, and LAOR refers to the large-aperture optical retarder used in the 1054-nm operation of the system.

Placing the frequency-conversion crystals near the target chamber presents two advantages over the LAOR option:

(a) high-power UV propagation is limited to less than 1 m, and

(b) the focus lens and blast shield are the only optics subject to possible coating damage due to high UV fluxes.

Fig. 17.1
Schematic of the OMEGA 351-nm conversion system. The second-harmonic generator (SHG) and third-harmonic generator (THG) crystals are shown mounted at the output of the last spatial filter (C/LAOR). The rejected alternative location near the focus lenses is indicated in the inset.



Unfortunately, placing the conversion system near the target-focusing lenses also presents some significant disadvantages, compared to the LAOR option, namely:

(a) limited UV-beam diagnostics (the UV diagnostics require retroreflection and a double-pass through the crystals), and

(b) the more complicated opto-mechanical design for such a system which would result in higher cost and longer design/construction time than the LAOR option.

Our favorable long-path-propagation experience with both GDL and OMEGA gave us confidence that UV-beam propagation from the laser bay to the target chamber would not present any serious problems. The primary trade-off between the two design options was between the diagnostic considerations and coating-damage risks.

An estimate of OMEGA flux levels in the UV indicates that at an energy level of 90 J at 351 nm, the highest estimated flux, 1.8 J/cm^2, occurs at the blast shield. The highest flux at the mirrors at the 90-J

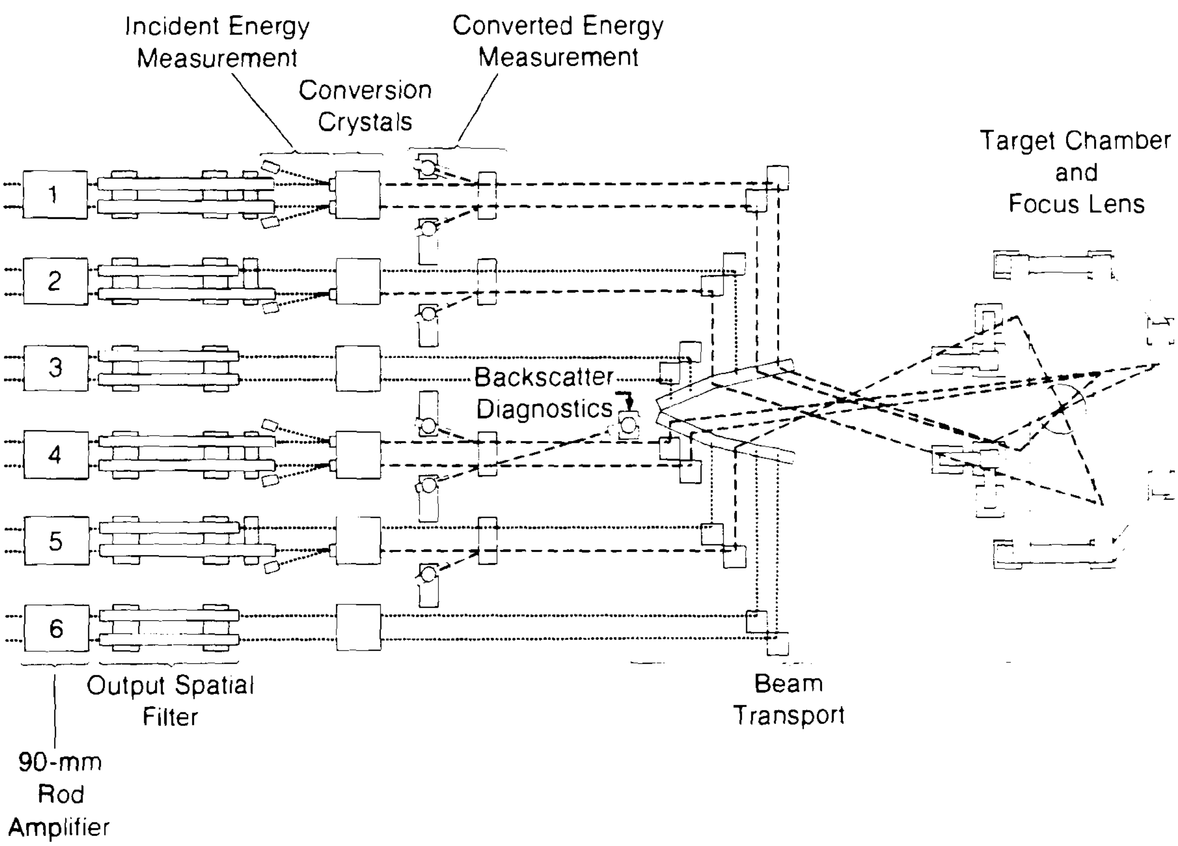


Fig. 17.2
Schematic of the overall beam layout for the OMEGA six-beam UV conversion. The beams shown in dashed lines are 351-nm beams.

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energy level is 1.1 J/cm². In these estimates, an average fill factor of 0.6 is assumed. An additional fill-factor multiplier of 0.56 is used to account for local hot spots from beam defects and diffraction rings.

Coating damage measurements at LLE and elsewhere indicate that flux levels of 1.1-1.8 J/cm² are below the damage threshold for state-of-the-art 351-nm AR and HR coatings.[3] Results of damage testing conducted at LLE show 1ω-3ω AR/0° coatings with mean damage thresholds ranging from 1.6±0.3 J/cm² to 2.1±0.3 J/cm². Measurements of 1ω-3ω HR/45° and 57° coatings show damage thresholds ranging from 1.80±0.24 J/cm² to 2.6±0.3 J/cm².

Based on these estimates and on the paramount need to have high-reliability and high-accuracy beam diagnostics, it was decided to implement the LAOR option for the frequency-conversion system. In the final configuration, the blast shield was left uncoated because the expected flux levels were too close to measured damage thresholds for AR coatings. We are investigating the option of coating these optics with Sol-Gel AR coatings (damage threshold ~ 4 J/cm²).

An overall schematic of the OMEGA system is shown in Fig. 17.2. The six-beam set chosen for 351-nm conversion has near-cubic symmetry.

OMEGA 351-nm Performance

Measurements of the 351-nm conversion efficiency of OMEGA were carried out for over 100 shots. The system (1054-nm) pulse width for the majority of these shots was held at 769±38 ps (FWHM). A compilation of all the single-beam data is shown in Fig. 17.3. The *MIXER*-code[4] prediction of the beam performance is also shown in Fig. 17.3 for comparison. In all shots to date, the experimentally measured, 351-nm conversion agrees well with that predicted by *MIXER*. A total 351-nm energy in excess of 388 J was produced; 30 shots produced a total 351-nm energy in excess of 250 J.

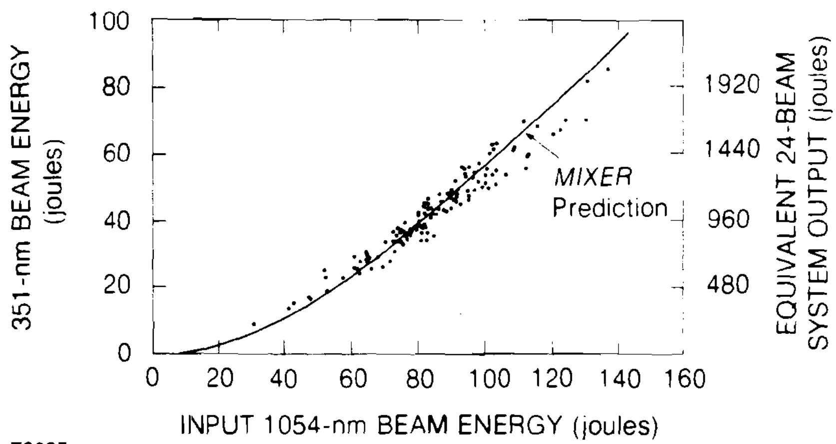

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Fig. 17.3
Summary of OMEGA 351-nm performance of individual beams. All beam data is shown here for the input pulse-width range 769±38 ps. Note the close agreement between the measured conversion and the MIXER[4] code prediction. The extrapolated output energy for a full 24-beam system is given by the scale on the right.

Near-Field and Equivalent-Target-Plane Diagnostics

To measure the equivalent-target-plane energy distribution at 351 nm and compare it to the distribution at 1054 nm, we constructed the system shown schematically in Fig. 17.4. This system makes use of a 10-m-focal-length lens to produce images of both the 351-nm and 1054-nm light at various positions along the focal axis.

A full equivalent-target-plane analysis of the 351-nm distribution is shown in Fig. 17.5. The nonuniformity modulation at both 351 nm and 1054 nm is comparable ($\sigma_{rms} \sim 27\%$). The intensity histogram in this figure shows that for the particular conditions of this shot (energy = 65.2 J, pulse width = 575 ps, and focus position = 1600 μm from best focus), the mean on-target intensity is 10^{14} W/cm^2, and the peak intensity is 1.74×10^{14} W/cm^2.

The near-field, 351-nm and 1054-nm beam distribution has also been recorded for the converted OMEGA beams. Figure 17.6 shows 351-nm, near-field data taken on the same beam as that of Fig. 17.5. The remarkable degree of uniformity ($\sigma_{rms} \sim \pm 8\%$) is a result of the high degree of alignment stability and optical quality of the OMEGA beams.

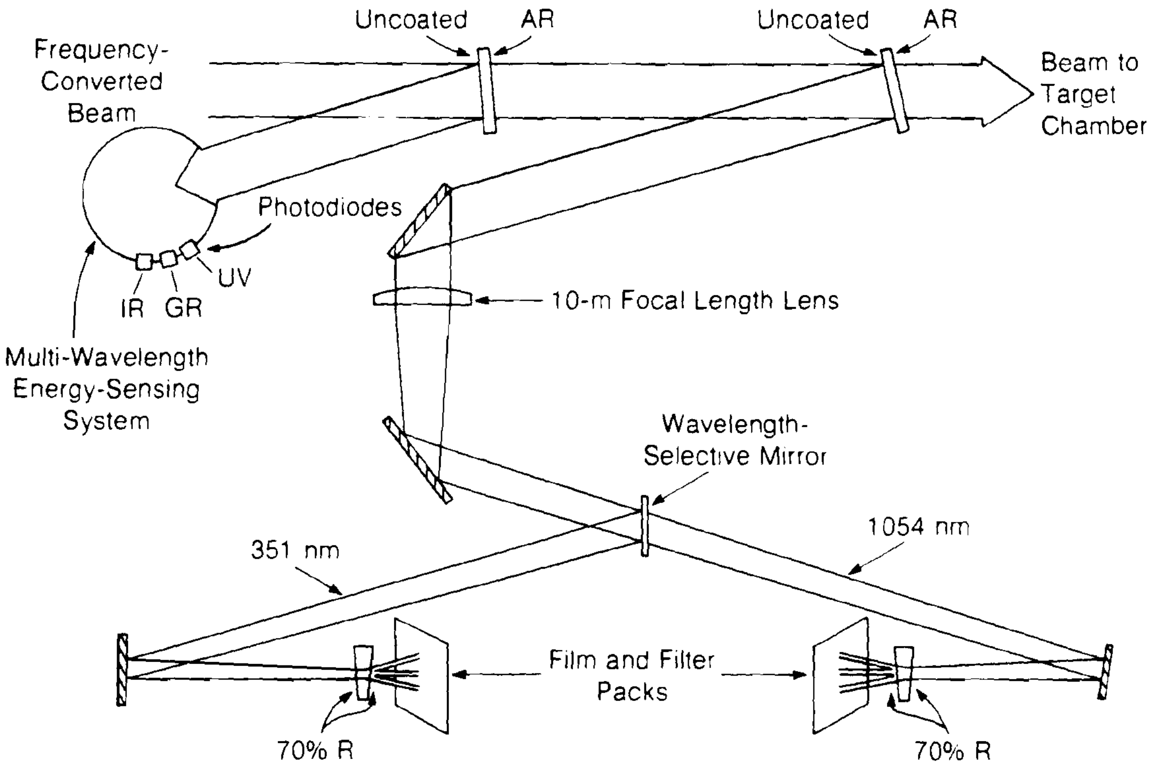

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Fig. 17.4
Schematic of the two-wavelength equivalent-target-plane system used to produce both 351-nm and 1054-nm images of the beam at various positions along the focal axis.

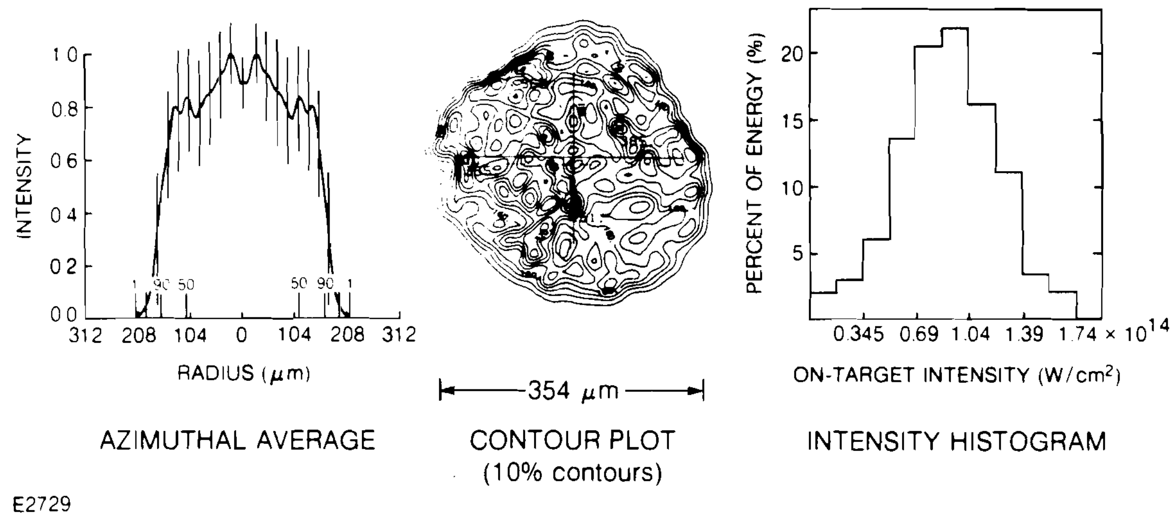

Fig. 17.5
Analysis of the equivalent-target-plane energy distribution for a single 351-nm beam at 1600 μm from best focus. A 719-ps IR pulse is converted to the 575-ps, 65.2-J UV pulse shown.

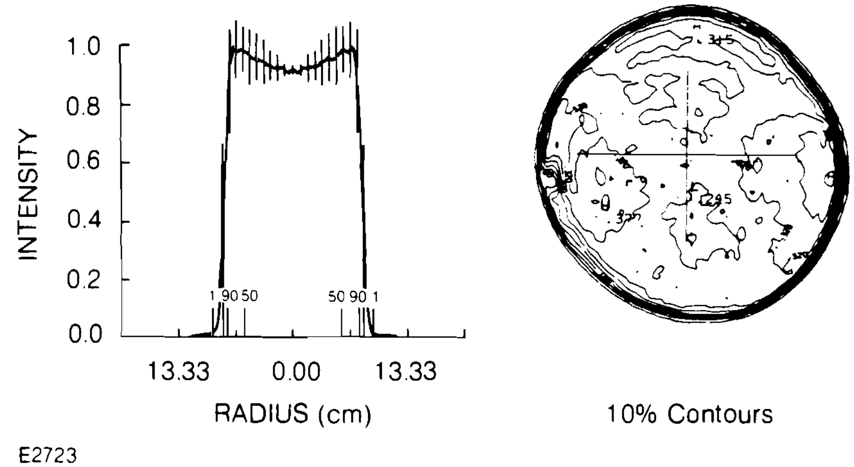

Fig. 17.6
Near-field photograph and analysis for the same beam as in Fig. 17.5 at an output-energy level of 58.8 J (351 nm).

Alignment System

Early in the design deliberations for the OMEGA conversion, it was decided to maintain the 1064-nm alignment capability of the converted system and, in fact, to try to do the full target alignment at 1064 nm. The use of auxiliary 351-nm lasers for multi-beam alignment was considered too expensive and unreliable. The transport optics were, therefore, specified to be two-wavelength capable (351 nm and 1064 nm).

The primary complications of doing 351-nm alignment with a 1064-nm beam are (a) chromatic shift and chromatic aberrations in the focus lens and (b) fundamental and second-harmonic rejection at the target plane.

In considering the first issue, two competing designs were calculated for the focusing optics. One of the designs was a single-element aspheric lens, and the other was a two-element aspheric/aplanat. It was found that the single-element aspheric design would have 1.2 waves of single-pass wavefront distortion at 1064 nm, compared with 0.25 waves at 351 nm, and that the two-element lens could produce diffraction-limited performance at both wavelengths. The consequence of the high wavefront distortion of the single-element design at 1064 nm is a poor focal resolution at this wavelength. We estimated that the focal resolution of the single-element lens would be $\pm 100\,\mu m$, compared to $\pm 25\,\mu m$ for the two-element lens. To confirm these estimates, we performed a test with a 14-cm, f/3, quartz aspheric lens designed for 351-nm operation. We found that even though the depth of field was about $100\,\mu m$ to $200\,\mu m$ at 1064 nm, an operator could reproducibly focus the lens at 1064 nm to within $\pm 12\,\mu m$ of a given location. The same operator could focus a diffraction-limited lens to similar accuracy. As a result of this study, we implemented single-element aspheric lenses on OMEGA.

The second issue, 1054-nm and 527-nm rejection at the target plane, was resolved very easily. The blue-beam focus of the 600-mm, single-element aspheric lens is approximately 34 mm ahead of the red-beam focus. Under most anticipated target conditions, the resulting intensity at 1054 nm is 10^{-3} of that at 351 nm. While solving the color separation problem, this large chromatic shift introduces some additional alignment problems, i.e., maintaining pointing stability as the lens is translated from red focus to blue focus. To solve this problem, we made use of the intrinsic high accuracy of the existing OMEGA lens holders. We installed a pneumatically driven ram to provide the large-scale shift between red and blue focus, and we used the existing fine adjustment to provide precision travel over 4 mm. Tests of the pointing resolution and stability and of the focus-position resolution and stability were carried out using x-ray imaging. From these measurements, we inferred a pointing accuracy and stability of $\sim \pm 10\,\mu m$ and a focusing resolution and stability of $\leq \pm 50\,\mu m$. This level of accuracy in focus pointing and stability is similar to that previously reported for the 24-beam, 1054-nm operation of OMEGA.

Summary

We have shown in this section that we have met or exceeded all of the DOE laser performance criteria, namely:

(a) We have produced in excess of 388 J in six beams at 351 nm at a pulse width in excess of 0.6 ns, we have taken 30 shots with six-beam energy in excess of 250 J, and we have on-target energy in excess of 298 J.

(b) The measured conversion for the system agrees with *MIXER*[4] calculations to within 10%.

(c) We have measured and successfully evaluated the equivalent-target-plane intensity distribution in both the UV and the IR. A high degree of uniformity is obtained.

(d) We have verified that the system-pointing accuracy and stability is $\pm 10\,\mu m$ and that the focusing resolution and stability is $\leq \pm 50\,\mu m$. The comparable 1054-nm numbers are $\pm 11\,\mu m$ and $\leq \pm 50\,\mu m$ respectively.

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4. R. S. Craxton, *Opt. Commun.* **34**, 474 (1980).