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TITLE: THE ANTARES FACILITY FOR INERTIAL-FUSION EXPERIMENTS: STATUS AND PLANS

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THE ANTARES FACILITY FOR INERTIAL-FUSION EXPERIMENTS - STATUS AND PLANS

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INTRODUCTION

In the last decade several increasingly powerful short pulse CO_2 lasers have been constructed at Los Alamos National Laboratory to investigate the feasibility of CO_2 as an inertial fusion driver. The advantage of CO_2, a gas laser with high rep-rate capability, electrical efficiency as high as 10%, and scalability to large energies, must outweigh important difficulties in target physics due to the copious production of suprathermal electrons if CO_2 is to be considered a viable driver option.

Since 1978, Los Alamos has used the 10-kJ, eight beam Helios laser[1] to perform a variety of experiments aimed at elucidating basic laser-matter interaction mechanisms and beginning to determine the scalability of CO_2-driven targets to high driver energies. Antares, currently under construction, will be the next CO_2 laser used to further the experimental ICF program. Scheduled for operation early in FY-84, the Antares laser is designed to provide 30-40 kJ in a nominal 0.7 ns pulse, utilizing 24 independently pointable beams. Since Helios is generally limited to ~ 5 kJ operation in most target experiments, this will provide a significant increase in the energy available for target experiments, enabling us to study the energy scaling of target interaction phenomena as well as to perform experiments which are energy-limited at Helios.

THE ANTARES LASER SYSTEM

Antares is a master oscillator-power amplifier system, consisting of a short pulse oscillator similar to that used in the Helios laser,[1] preamplifiers, intermediate driver amplifiers, and a pair of large electron-beam-controlled discharge power amplifiers. A multiline oscillator for pulse lengthening and shaping is being developed.

Each power amplifier is double-passed for efficient energy extraction and produces an annular array of 12 trapezoidal beams (sectors) for a total of 24 beams, which are independently pointed and focused on target in a six-sided illumination pattern. A schematic of the facility beam path is shown in Fig. 1. The optical system is designed to focus 80% of the energy of each sector into a 300 μm diameter spot with a pointing error of ± 25 μm at the target (each sector is an effective f/6 beam). The final turning and focusing mirrors are mounted on a large space frame within the 8-m diameter target chamber. In order to eliminate parasitic oscillations[2] which extract energy before short pulse amplification can take place, the Antares amplifiers are pumped to a gain of $gL \approx 7$ in 1.5 μs and the power amplifiers are separated from the target by 60 meters to reduce the number of available round trips for parasitics during the pump time. (There is also the provision for a saturable absorber gas cell in the power amplifier.) The sections below will discuss the details and status of major components of the Antares laser system.

FRONT END SUBSYSTEM

The Antares front end, shown schematically in Fig. 2, originates with a single longitudinal mode gain-switched oscillator with three pockels cells in series to provide an energy contrast ratio of approximately 10^{10} at the output of the front end; this contrast ratio is sufficient to provide negligible prepulse on target for the highest anticipated system small signal gain. A triple-passed Lumonics double-discharge TEA laser amplifies the nominal 1 ns pulse; the beam is then split and injected into a dual-beam e-beam-controlled driver amplifier module. Each gain region of the dual beam module is triple-passed using an on axis cassegrain system for efficient extraction. The output of the driver amplifiers is a 90 J annular beam with 9 cm ID and 15 cm OD.

At the present time, the short pulse oscillator is operational and a three line multiple-cavity multiline oscillator is under construction. The multiline oscillator will extract energy on lines widely separated in the rotational manifold, enabling us to overcome the inherently short pulse

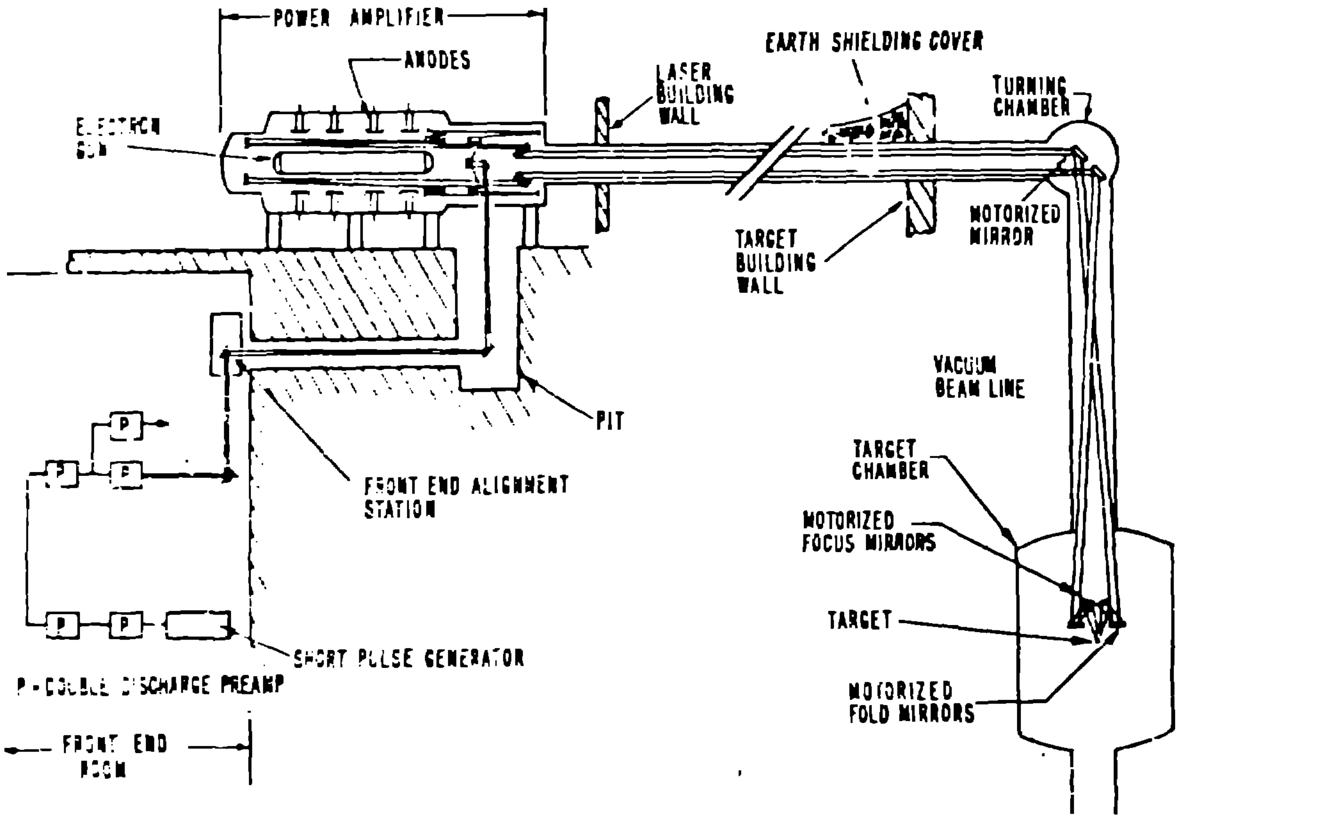

Fig. 1 Facility Schematic

nature of heavily saturated amplifiers to tailor the pulse shapeon target. Both driver amplifier discharges are electrically operational and, on one beamline, more than 500 shots have been fired extracting ~ 100 J. This exceeds specifications and is sufficient to drive the power amplifier for energy extraction tests. The repitition rate of the front end system is approximately 3 min/shot, limited by charging times for the driver amplifier; total alignment time from a dead start is 2 hours. Overall reliability of the front end is currently 95% and is improving toward the specified 99%.

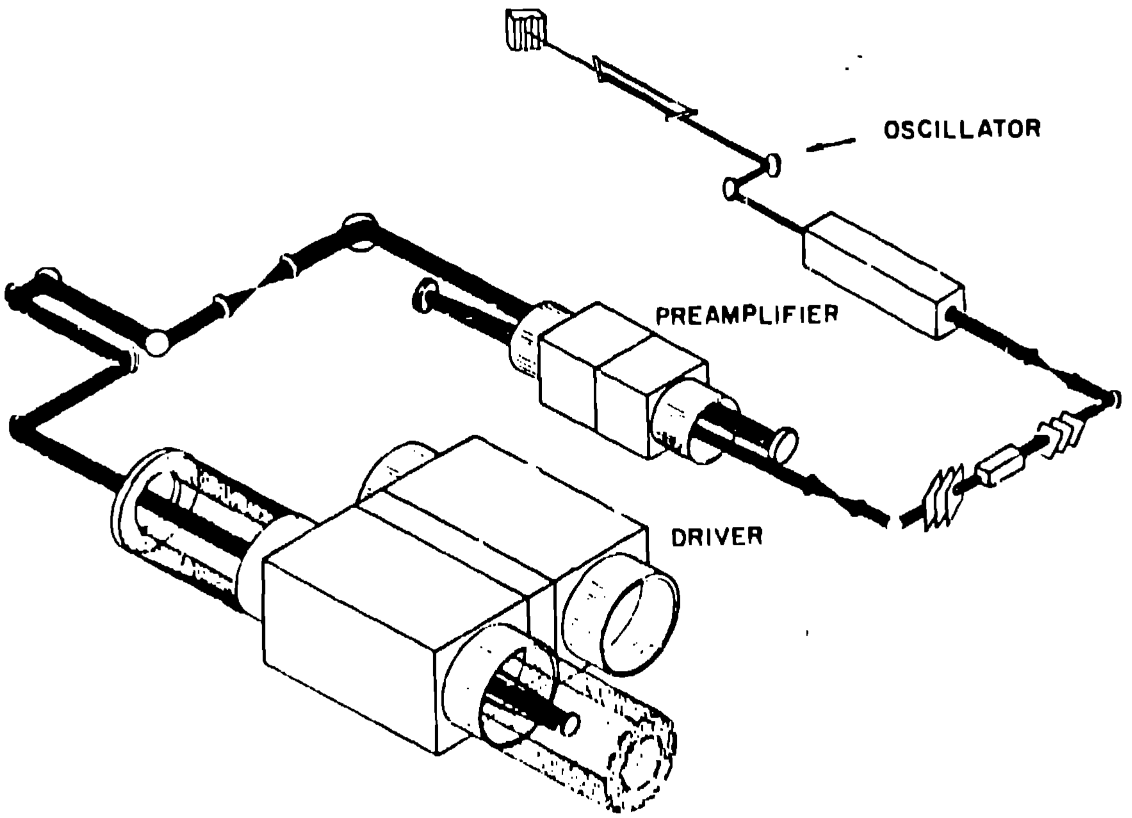

Fig. 2

Front end schematic.

POWER AMPLIFIER SUBSYSTEM

The two annular beams from the front end are directed into the two large power amplifier modules (Fig. 3) where they are each split into 12 trapezoidal beams. Each power amplifier 4 meters in diameter and 18 meters long, weighing 150 tons, consists of one central 450 kV electron gun (shown before insertion into the power amplifier in Fig. 4) surrounded by 12

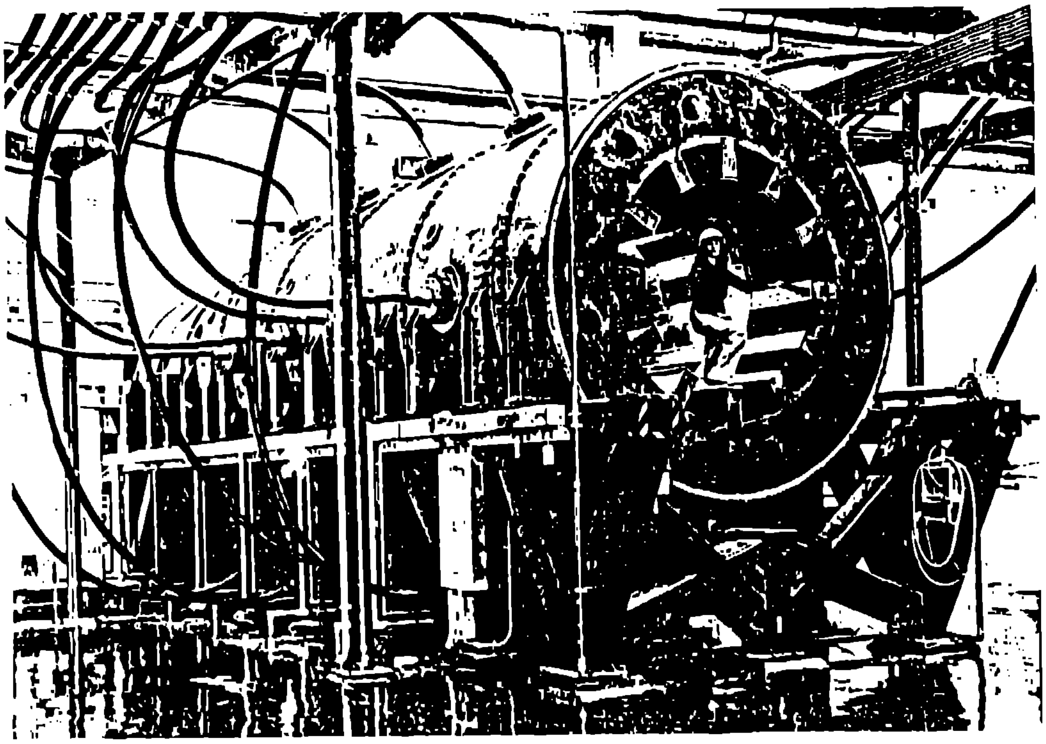

Fig. 3
Power amplifier module before insertion of electron gun.

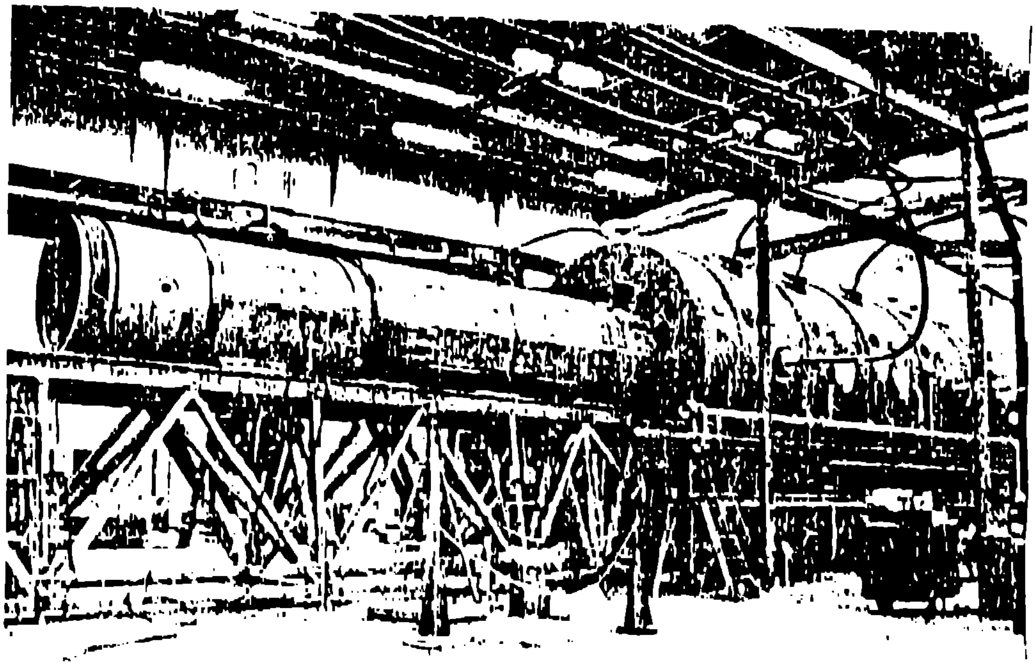

Fig. 4.
Electron gun showing the foil windows between the gun vacuum and the laser gas.

discharge regions. The electron gun is gridded to provide voltage-independent current control and produce the required 50 mA/cm^2 beam density appropriate for optimal preionization of the 1800 torr $CO_2:N_2/4:1$ amplifier gas mix. The gun is fed triaxially. To limit magnetic field effects, the discharge region is divided into four sections along its length providing, in effect, 48 discharge chambers per power amplifier module. Each power amplifier section (four per module) contains one continuous cylindrical anode for all 12 discharge regions and is energized by a 10-stage marx generator with an open-circuit voltage of 1.2 MV, an energy storage of 300 KJ, and an inductance of 2.5 μH to match the gas discharge impedance. A cutaway drawing of a section of a power amplifier module is shown in Fig. 5.

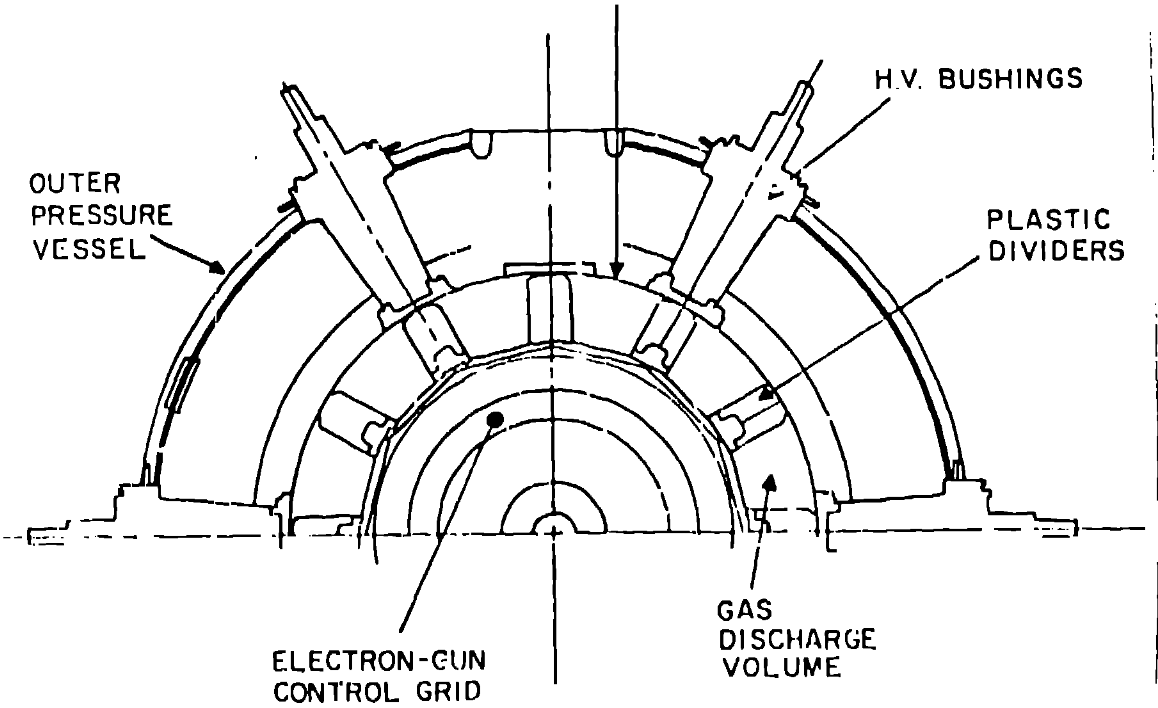

Fig. 5
Cutaway view of a section of the power amplifier.

The optical path through the power amplifier is shown in Fig. 6. Each of the 12 sectors double passes the gain region of the power amplifier; these sectors are then compressed by periscopes into an annular "beam" (1.7 meters O.D. x 1.0 meters I.D.) which passes through large NaCl windows into an evacuated beam transport tube towards the target chamber. A vacuum spatial filter within the power amplifier provides passive protection against retropulse damage to the front end optics.

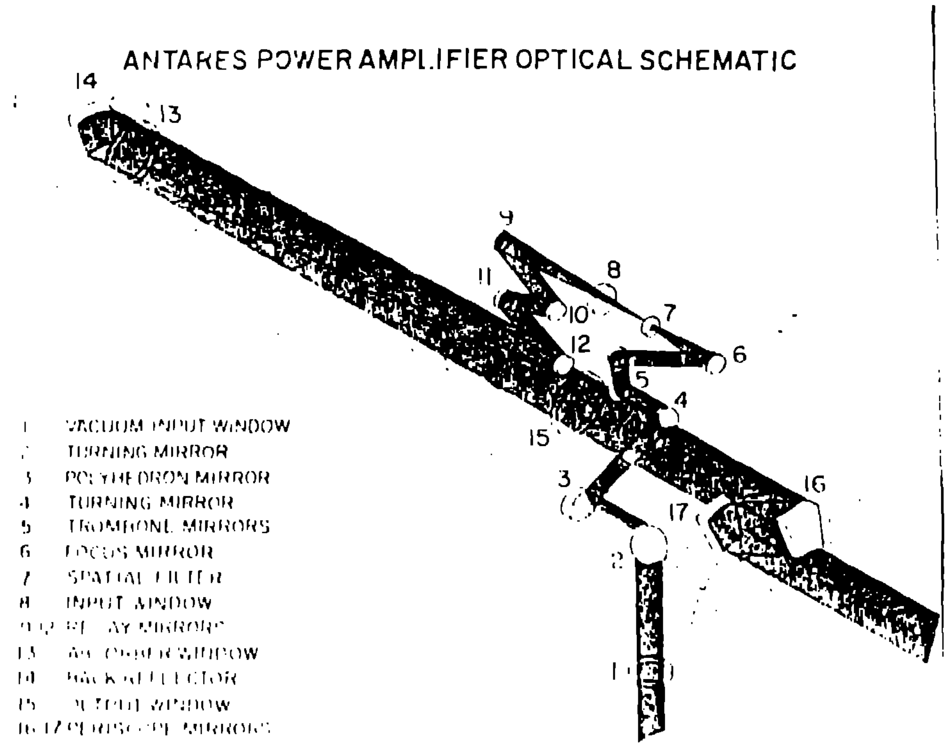

Fig. 6

At the present time one power amplifier is electrically operational and has undergone extensive testing. Net small signal gain $g_0 L = 6.4$ has already been demonstrated, in agreement with predictions for the current operation of the electron gun at 400 kV. Operation of the electron gun at full design voltage should, based on these tests, enable the Antares amplifiers to approach the maximum design point output of 40 KJ. Improvements on the electron gun designs have been implemented in order to reach this goal. As of this writing, full beam optics for the first beamline are being readied for insertion and initial alignment in the power amplifier. The electron gun for the second beamline incorporating the above mentioned design improvements has undergone preliminary tests at 470 kV.

TARGET CHAMBER AND FOCUSING OPTICS

The Antares target chamber is a 4 m radius, 7 meter long cylindrical vacuum vessel (Fig. 7) containing a space frame on

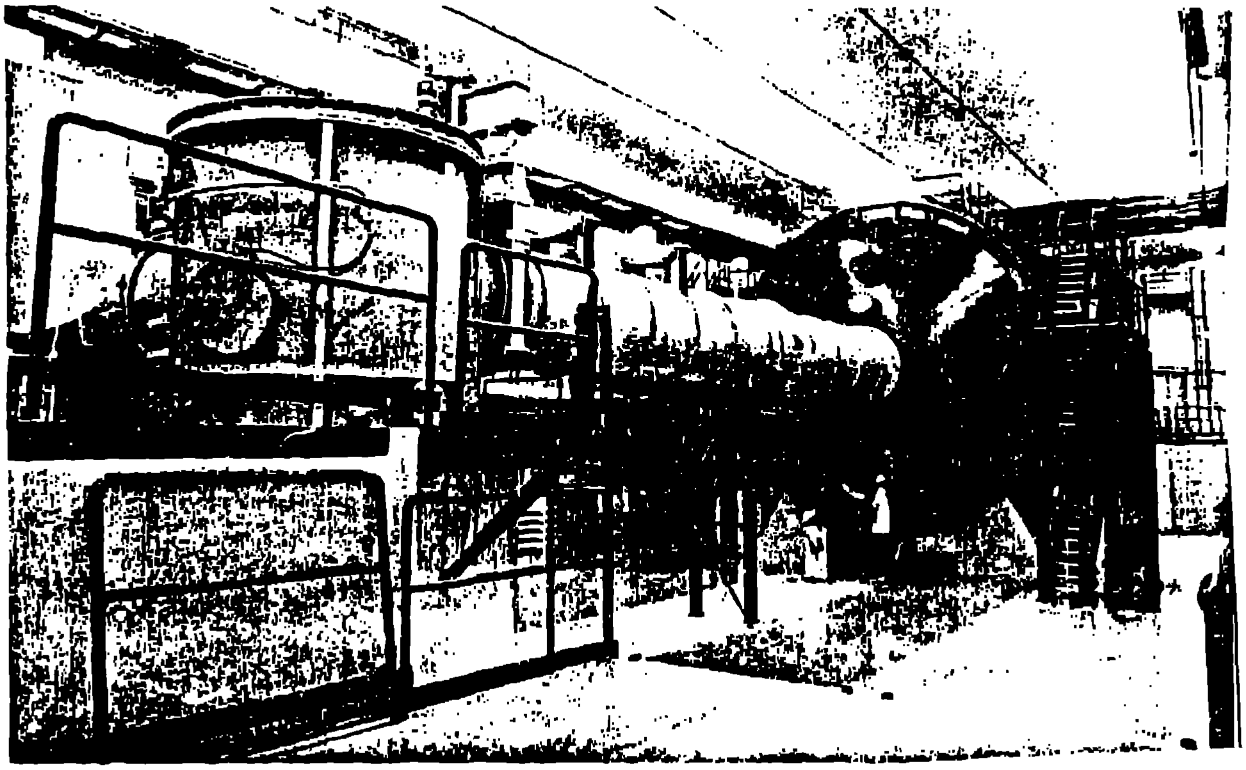

Fig. 7.
The Antares target chamber and evacuated beam tube.

which are mounted 24 turning mirrors and 24 f/6 focusing paraboloids. Target irradiation is six sided with beams arranged in clusters of four, as shown in Fig. 8. As are all large mirrors in the Antares system, the turning and focusing mirrors are single-point diamond turned copper plated on aluminum substrates. The target chamber utilizes cryogenic and turbomolecular pumps to achieve a base pressure of 2 x 10^{-6} torr with a pump down time of 8 hours. In order to avoid venting the target chamber between shots, targets are inserted through an airlock mechanism which enables target replacement in 10 minutes with a placement precision of 5 μm. Alignment of the targets is performed using a pair of large reference telescopes, which have a resolution (target placement error) of 6 μm and a field of view of 1 cm diameter.

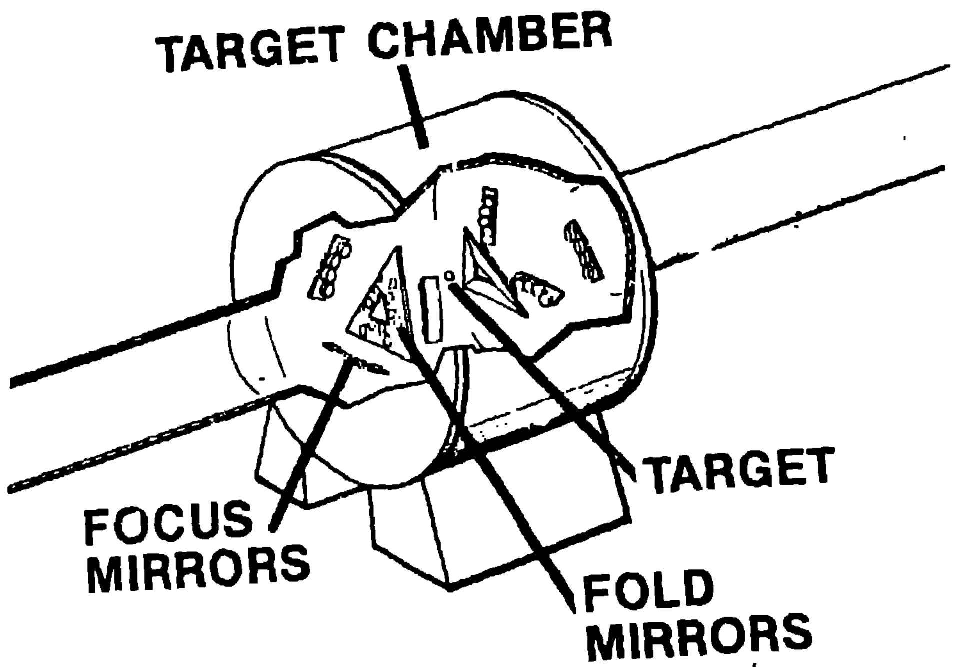

Fig. 8

Final beam pointing and focusing optics.
Target illumination is six-sided.

Alignment of the laser beams to the target is accomplished by a computer-controlled automatic alignment system which can perform a complete realignment of all 24 beams in 2 hours with a pointing precision of 25 μm (compared to a 300 μm beam spot size). Beam centering along the optical paths is accomplished by observing light sources located at the center of important optical elements; pointing to the target is achieved by observing a movable fiber-optic light source at the target position which is gimbaled to point at all 24 focusing mirrors in turn.

At the present time, the target chamber vessel and vacuum system are complete, and installation and alignment of support structures for the optical components is underway. The target insertion mechanism, which is a modification of a design previously tested and now used at Helios,[3] is being fabricated, as are the large optical reference telescopes.

TARGET DIAGNOSTICS

Experiments on Antares will assess the efficiency with which 10 μm light can be utilized to drive hydrodynamic implosions with appropriate levels of preheat, as an extension of current Helios experiments. The initial operation of the facility in early FY-84 will be aimed at verifying the energy scaling of important features of the laser-target interaction: absorption and energy balance (including fast ion generation), hot electron deposition, and target heating.

In order to achieve these goals we are fielding the following initial set of diagnostics: (1) A pair of x-ray pinhole cameras for verification of beam alignment on target. These cameras are inserted into the chamber through an air-lock mechanism to enable retrieval of film and changes of pinholes and filters between each shot. Pinhole imaging is also used to determine the spatial distribution of hot electron deposition in the target. The pinhole cameras will view the target from the ends of the chamber near the beam transport tubes.

(2) An array of 26 plasma calorimeters to determine the absorbed energy by measuring the energy in the ion expansion (time-integrated). Several calorimeters will be filtered, e.g. with 0.5 μm Ni, to determine the energy invested in the fast ion expansion (0.5 μm Ni stops 100 keV protons). These calorimeters will be distributed in an arrangement which provides roughly uniform sampling of the ion angular distribution.

(3) A 10-channel filter/scintillator/photodiode hard x-ray spectrometer known by the acronym APACHE.[4] Filters and scintillators provide broadband channel response in the range 30-500 keV. A fit to the signals from individual channels (assuming a Maxwellian bremsstrahlung spectrum) determines the hot electron temperature and the amount of hot electron energy collisionally deposited in the target. The detector system provides 10 ns resolution and is therefore time-integrated on the time scale of the laser interaction, although time resolved compared to electrical noise background.

(4) A 7-channel filtered x-ray diode array (MULTIFLEX)[5] with ~ 250 ps system risetime. The photoelectric responses of the aluminum photocathodes and filter transmission characteristics enable coverage of the spectrum between ~ 30 eV and ~ 2 keV. MULTIFLEX enables us to study target surface temperature and determine the heating due to hot electron deposition.

(5) A soft x-ray collimator comprised of an array of 7 primary pinholes (~ 150 μm diameter) and a cleanup collimator of 7 secondary pinholes (~ 500 μm diameter). This collimator

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(5) A soft x-ray collimator comprised of an array of 7 primary pinholes (~ 150 μm diameter) and a cleanup collimator of 7 secondary pinholes (~ 500 μm diameter). This collimator serves to limit the field of view of the MULTIFLEX diodes to a common 400 μm diameter spot in the target plane, enabling a determination of the brightness temperature of the target surface unaffected by considerations of source size. The collimator pinholes are located 10 and 20 cm from the target and are optically aligned with the MULTIFLEX diodes to a positioning accuracy of 25 μm. Both MULTIFLEX and APACHE view the target from the "equator" of the target chamber.

All of these diagnostics are modifications of tested instrumentation currently in use at Helios, but represent only a fraction of the tested diagnostics used at that facility, which include a variety of spectrographs, Faraday cups and Thomson parabolas, and optical diagnostics. Many of these diagnostics will be added during the operational phase of Antares. Designs for the pinhole cameras are complete, and fabrication of the plasma calorimeters is well under way. Modifications of MULTIFLEX and APACHE are undergoing engineering design. The instrumentation is scheduled for installation and checkout prior to Antares turnon in early FY-84.

CONCLUSIONS

Antares is a large, 30-40 kJ CO_2 laser system which will provide a base for experiments to determine the efficiency with which 10 μm light can be used to drive target implosions while maintaining an acceptable level of preheat. Construction of the facility is in the final stages and diagnostics for initial experiments are being designed and constructed with operations scheduled to begin early in FY-84. After an initial shakedown period, we expect to perform a series of measurements to determine the energy scaling of hot electron temperature and target coupling efficiency in selected set of targets including simple spheres. We also expect to continue experiments, now planned for Helios, to determine whether CO_2-produced ions are appropriate for driving inertial fusion targets with acceptable efficiency (Helios experiments have demonstrated that as much as 40% of the incident light can be converted to fast ions). Details of these experiments, as well as plans for further experiments, are still being defined.

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