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HELIOS, A 20 TW CO_2 LASER FUSION FACILITY*

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Since June 1978 the Los Alamos Scientific Laboratory's Helios CO_2 laser fusion facility has been committed to an experimental target program to investigate the feasibility of laser produced inertial confinement fusion. This system is briefly described, and preliminary experimental results are reported.

INTRODUCTION

Our greatest potential energy resource lies in the fusion area. Today there exists a major research effort directed toward the development of a fusion reactor based on inertially confined thermonuclear plasmas produced by laser or particle beam heating. The CO_2 laser fusion effort at the Los Alamos Scientific Laboratory (LASL) began in 1969 with the expansion of a small program which had existed since about 1967. Since that time this effort has expanded into a balanced research program aimed at a comprehensive investigation, both theoretical and experimental, of laser-induced fusion for energy production. At the LASL there exist two large CO_2 laser systems, Gemini and Helios, actively pursuing fusion research; a third system, Antares, is scheduled for completion sometime in the early 1980s. The Gemini system is a two-beam pulsed laser system which operates at a maximum output power of about 1 terawatt. In January 1977, the first D-T fusion neutrons produced by pellet implosion using CO_2 lasers were observed at the LASL Gemini system. Antares has been designed to produce 100-200 terawatts of power and has a goal of "scientific breakeven" (i.e., thermonuclear energy output = laser energy incident on target[1]. This paper discusses the Helios laser facility and the recent target results obtained there.

DESCRIPTION OF THE HELIOS FACILITY

The Helios Laser Facility is the world's most powerful gas laser system. On its first full system shot on April 12, 1978, it set a world record with a total output power in excess of 15 terawatts. Two months later it was fired at powers in excess of 20 terawatts.

An overhead view of the Helios main floor experimental area is shown in Figure 1. Four large power amplifier modules, located in each corner of the main floor experimental area, surround the centrally located target chamber.

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*Work performed under the auspices of the U. S. Department of Energy.

Each power amplifier module consists of two separate amplifiers which form the final amplifier stages for two separate beams. The eight input beams used to drive the power amplifiers are obtained by beamsplitting a single pulse of energy produced in an area separate from the main floor experimental area. A photograph of this area commonly referred to as the "front end" is shown in Figure 2.

In the front end, an oscillator and six preamplifiers, in conjunction with an appropriate optical transport system, produce four low-energy beams (approximately 400 mJ each, 2 cm in diameter) which are transported to the main floor experimental area, where a subsequent beam splitting produces the eight input beams to the power amplifier modules. Each of the eight input beams to the power amplifiers is passed three times through the gain medium of the power amplifier, and emerges with an output energy which can be varied up to a maximum of approximately 1300 joules per beam. These beams (now 34 cm in diameter) then enter the target chamber where they are focused by appropriate optics onto a target. An internal view of the target chamber is shown in Figure 3. In this photograph, the large copper mirrors which focus the beams onto the target, as well as some of the target diagnostics, can clearly be seen. A target insertion mechanism, which can be operated external to the vacuum system, is also visible slightly to the left of center in the photograph.

The Helios laser control system incorporates such features as computer controlled automatic beam alignment and automatic data acquisition and gives us the ability to fire the entire system roughly once every half hour. The major portion of the control system resides in the main control room. The photograph in Figure 4 shows a view of the main control room with an operator seated at the computer control console. The actual computer is located in an electrically shielded enclosed room behind the operator and communicates via fiber optic links to various microcomputer controlled substations located throughout the system.

A summary of the current operational characteristics of the Helios system is given in Table 1.

Table 1

Operational Characteristics of Helios

Laser Energy (kJ)	1 - 10
Prepulse Energy (μJ)	< 20
Pulsewidth (FWHM, ns)	0.5 - 1.0
Cycle Time Laser (min)	5
Target Shot Rate (# /day)	10
Efficiency (Laser Energy Out/ Total Electrical Energy Used)(%)	1
Wavelength (μm)	10.6
Max. Target Irradiances (W/cm^2)*	2.4 x 10^{16}
80% Encircled Energy Diameter (μm)*	300
Solid Angle Available for Diagnostics (sr)	0.9 x 4π
Focusing Optics	f/2.4 off-axis parabola

*Calculated value based on reduced interferograms of actual components and diffraction propagation [1].

RECENT EXPERIMENTS

Since June 1978 the Helios laser system has been used to perform a series of carefully planned target experiments, aimed at extending our understanding of the laser-plasma interaction. These experiments form an intermediate and necessary step toward the overall goal of demonstrating the feasibility of laser-induced fusion as a viable future energy source. The photograph in Figure 5 shows a typical glass microballoon (GMB) target which has had holes burned through its surface by firing at the target with extremely weak laser pulses. Such experiments provide a vivid test of the accuracy of beam alignment [2]. Experiments performed with similar such targets with high powered pulses incident, provide a means of testing our understanding of inertially confined laser-produced plasmas, and the resultant thermonuclear energy production. Initial experiments at the LASL and elsewhere were aimed primarily at the demonstration of thermonuclear burn conditions. Today the emphasis is on the demonstration of the ability to produce high density core compressions in target implosions. Only recently have experiments been able to unequivocally demonstrate compressed core densities in excess of liquid density ($\rho \geq 0.2$ g/cm^3).

The first experiments performed on the Helios system have involved two classes of targets which, though quite similar in appearance, behave quite differently from the physics point of view. The first class of targets is similar to that shown in Figure 5 and consists of spherical thin shelled (typically 1 μm thick) glass microballoon (GMB) targets, of radius 100 - 200 μm, and filled to a 50% deuterium - 50% tritium fuel pressure of 10 - 30 atm. This class of targets behaves in a mode often referred to as the "exploding pusher" mode. These targets were the first type of targets used which produced observable thermonuclear burn. Typically, the plasmas produced in exploding pusher experiments are characterized by fairly low-density cores ($\rho \sim 2\times10^{-2}$ g/cm^3), resulting from a near instantaneous heating of the fuel, followed by a more or less isothermal compression brought about by the exploding pusher (glass) - fuel interface. Plasma ion temperatures are in the keV range and the resultant thermonuclear burn is easily observable. A summary of a recent exploding pusher target shot taken on the Helios system is given in Table 2.

Table 2

Exploding Pusher Target Shot Summary
(Shot #88110708)

Target Parameters	
Radius (μm)	190
Shell Thickness (μm)	0.9
Fill Pressure (atm)	8
Fuel Mix	50% D_2 - 50% T_2
Laser Parameters	
Energy (kJ)	2.4
Pulsewidth (FWHM, ns)	0.6
Peak Power (TW)	3.5
Spot Size (μm)*	300
Peak Intensity (W/cm^2)*	2.4×10^{16}
Measured Plasma Parameters	
Neutron Yield	3.5×10^{8}
Compressed Density (g/cm^3)**	1.5×10^{-2}
ρR (g/cm^2)**	1.5×10^{-4}
Calculated Plasma Parameters***	
Neutron Yield	4.2×10^{8}
Compressed Density (g/cm^3)	1.3×10^{-2}
ρR(g/cm^2)	1.3×10^{-4}

*Calculated value based on a computed 80% encircled energy diameter of 300 μm [1]
**Inferred from measurements of compressed core radius
***Calculated on basis of simple exploding pusher model [3]

Exploding pusher experiments have provided a great deal of valuable plasma data, and have aided in the development of sophisticated plasma diagnostics. This class of targets however does not represent the most plausible path to the achievement of "scientific breakeven" since this requires a product of density ρ times compressed fuel radius R of order $\rho R \geq 0.3$ g/cm^2[4], which requires much higher densities ($\rho \geq 10^2$-10^3 g/cm^3)[5] than generally thought achievable in exploding pusher targets.

The second class of targets, referred to as "high-density" targets, consist of a GMB identical to the exploding pusher variety, but have an additional external low-density plastic coating of thickness which can be varied from 0 to 200 μm. The "high-density" targets are aimed primarily at achieving relatively high plasma core densities ($\rho \geq 4$ g/cm^3). The external plastic coating serves a twofold purpose in this case: (1) it shields the interior fuel, preventing a significant preheat prior to compression; (2) it provides an efficient means of converting absorbed laser energy into compressional motion. These characteristics allow an adiabatic compression heating mode leading to inherently higher achievable core densities than the essentially isothermal compression mode of the exploding pusher targets.

From an experimental point of view the "high-density" targets have the following advantages: (1) they are relatively easy and inexpensive to fabricate; (2) they are relatively straightforward to diagnose because the neutron yields are substantial and the low Z coating is at least partially transmitting to the x-rays generated by the imploding glass shell, making x-ray core diameter measurements possible; (3) by varying the plastic thickness it is possible to go continuously from the exploding pusher mode to an adiabatic compression mode, allowing for a much easier extrapolation in both experimental and theoretical results.

The recent positive results obtained with these targets have in fact generated an excitement in the laser fusion community akin to the observation of the first laser-produced thermonuclear fusion events. A summary of the preliminary results obtained with these targets is given in Figure 6. Note that as the plastic thickness (labeled "ablator thickness" in Figure 6) is increased the fuel density increases, but the neutron yield decreases. This decrease in neutron yield is due to the correspondingly lower fuel temperatures which occur as the thickness is increased and the incident laser energy is held constant. As can be seen from the data presented in Figure 6, the agreement between theory and experiment is good for reasonable values of calculational parameters. These results would seem to indicate that not only is it possible to achieve high density adiabatic compressions via absorption of laser energy, but perhaps equally important to the success of the inertial confinement fusion program, that we have the requisite theoretical capability to design the targets which will be required to achieve breakeven and beyond. Although no one perhaps feels more acutely the difficulty of the obstacles which lie ahead in a program than those committed to its success, the recent results obtained on the Helios system have been cause for an optimism which we can only hope will be self-fulfilling.

SUMMARY

The development of fusion energy as a future energy source depends at present on the success of the research now being carried on in inertial and magnetic confinement. At the Los Alamos Scientific Laboratory, the 20 TW Helios CO$_2$ laser fusion facility has been committed to the determination of whether inertial confinement fusion with lasers holds this promise. While the recent high-density experimental results obtained on the Helios system must be regarded with cautious optimism, the significance of these results should not be underestimated.

ACKNOWLEDGEMENTS

The Helios laser facility and the recent experimental results reported here represent the dedicated and coordinated effort of a large number of people. A good proportion of these people are, or were, members of the Laser Division, primarily in Groups L-1, L-4, L-6, L-7 and L-9; a significant number, however, belong to other divisions. In particular I would like to acknowledge our debt to those members of J-Division, P-Division, WX-Division and TD-Division whose efforts have brought us to this exciting stage in fusion research.

I would like to especially thank the team captain of the exploding pusher experimental series, Dr. Damon Giovanielli, and the team captain of the high-density experimental series, Dr. Tai-Ho Tan, for their permission to quote their experimental results and for their valuable discussions.

Most of all I wish to acknowledge the effort of that dedicated group of people collectively referred to as the "Helios staff" who for the last four years have struggled continuously in their efforts to make the Helios facility a reality.

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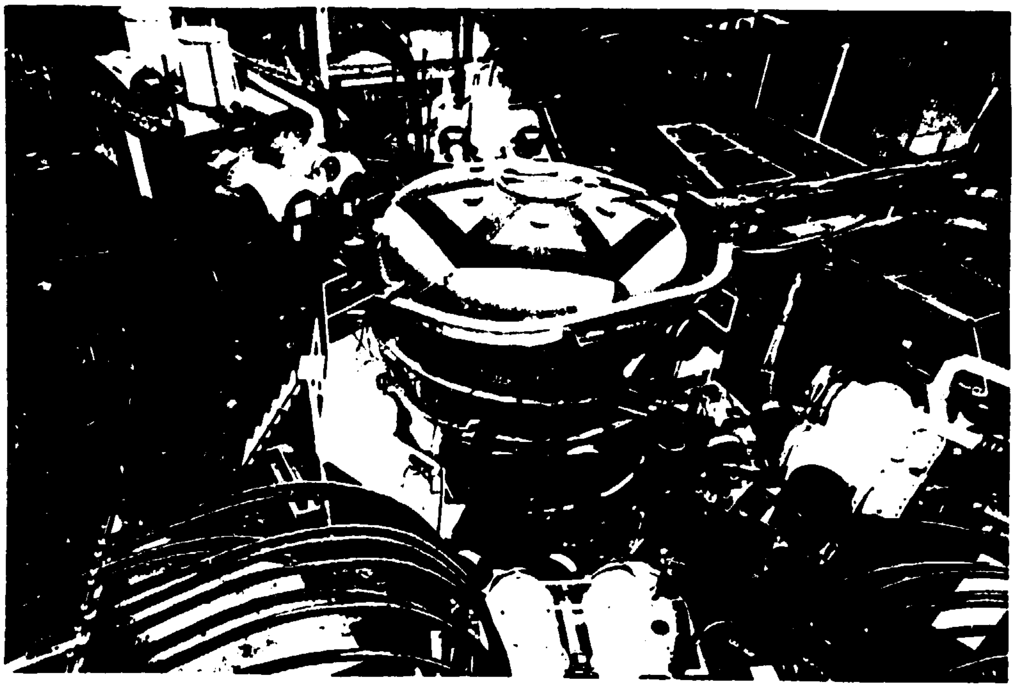

Figure 1. Helios main floor experimental area

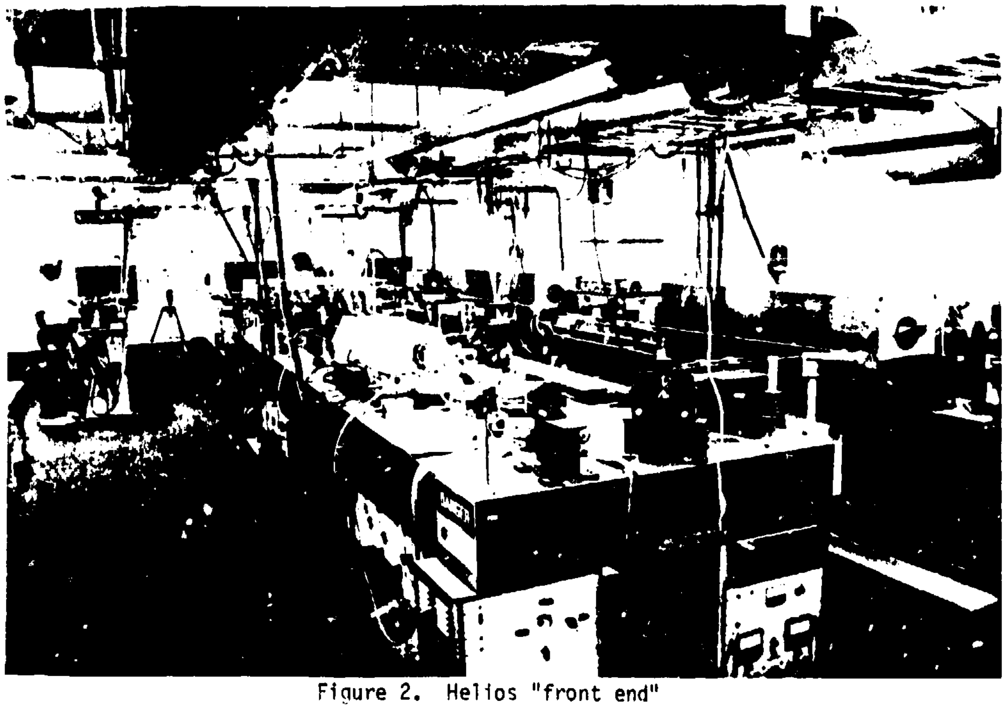

Figure 2. Helios "front end"

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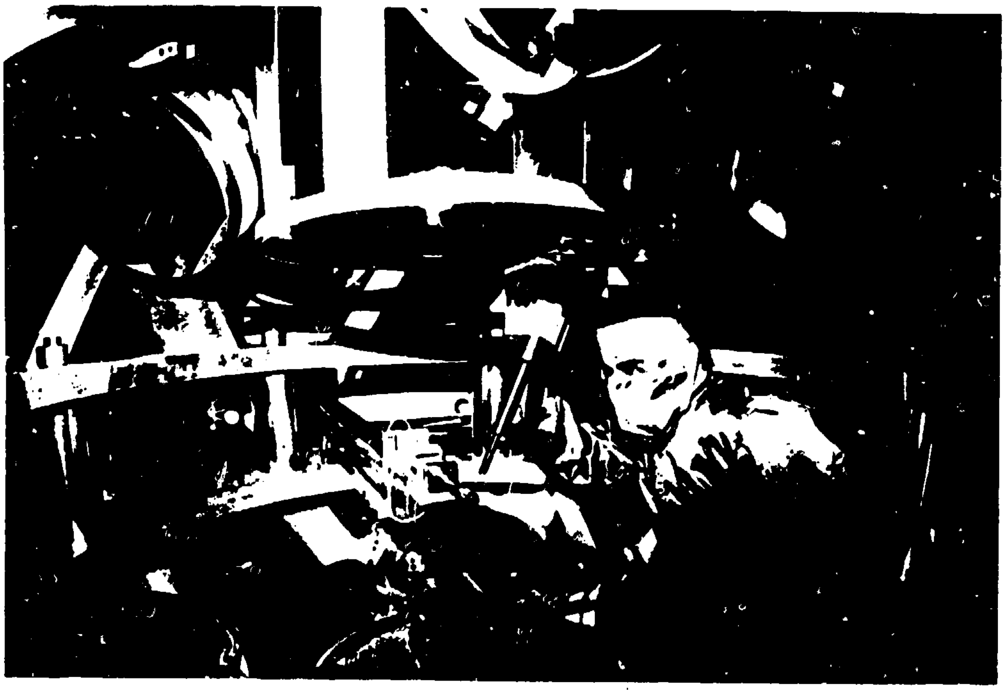

Figure 3. Internal view of Helios target chamber

Figure 4. Helios main control room

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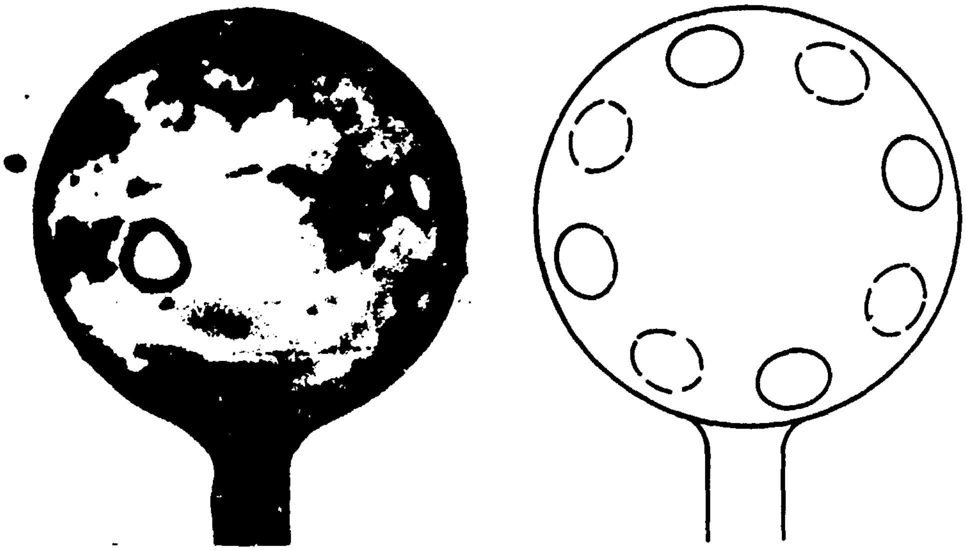

Figure 5. Glass microballoon target showing eight holes made by firing laser at low power

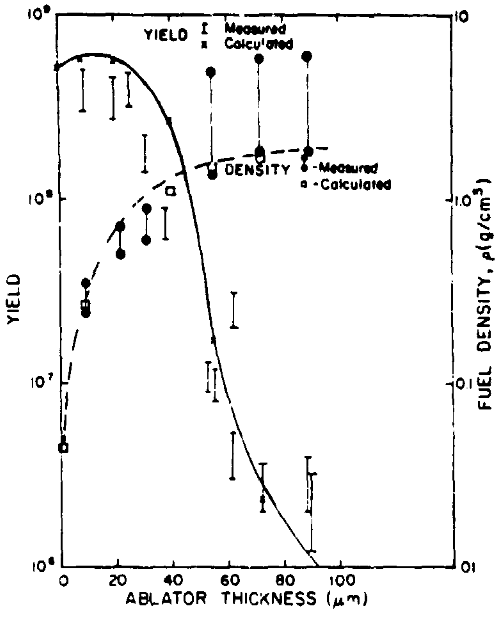

Figure 6. Experimental results obtained on "high density" targets showing neutron yield and core density as a function of plastic thickness (ablator thickness)

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ABSTRACT

Currently, a CO_2 laser is regarded by many as the most promising candidate for a laser fusion driven reactor system. The Los Alamos Scientific Laboratory's Helios Laser Fusion Facility, which became operational in April 1978, is the world's most powerful CO_2 laser; and as such, is being observed with great interest by those involved in the laser fusion area.

In this talk I will discuss the operational characteristics of the Helios Laser Fusion Facility, with particular emphasis on those features which make this system unique and which relate directly to the overall laser fusion program in this country. I will also discuss some of the recent experimental results which have been obtained with the Helios Laser Fusion Facility and the importance they bear on our goal to achieve a "scientific breakeven" laser fusion system.

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*Work performed under the auspices of the U. S. Department of Energy.