Laser Fusion Program

at Los Alamos

LOS ALAMOS SCIENTIFIC LABORATORY

LASL-79-29

Cover

Optical interferometry is used to inspect glass microballoons for quality prior to use in laser-fusion targets. In this photograph we show the optical interference pattern of a high-quality glass microballoon glued to a glass support stalk.

Introduction

The Laser Fusion program at the Los Alamos Scientific Laboratory (LASL) is pursuing the dual goal of investigating commercial and military applications of inertial confinement fusion. For both goals it is essential to achieve scientific breakeven, that is, a fusion yield that equals the laser energy input to the fuel pellet.

The advanced short-pulse, high-energy carbon-dioxide lasers we at LASL are using in our fusion research show promise of meeting these goals and appear feasible for use in commercial fusion reactor systems. Carbon-dioxide lasers have a demonstrated 2% efficiency (with potential 10% efficiency) and, because they use a gaseous medium, are capable of operating at the high repetition rates that will be required in a power plant.

Our first CO_2 laser system, the Single-Beam System, was designed in 1970, began operation in 1973, and was phased out in 1977 after providing much information on performance of the CO_2 laser and on the interaction of lasers with matter. Two major laser systems are now operating: Gemini, a two-beam system and Helios, an eight-beam system.

Helios, which became operational in April 1978, is being used in pellet irradiation experiments that will lead to the design of a breakeven target for our ten times more powerful Antares laser system. Gemini, which produced our first fusion neutrons in 1977, is being used for important laser-plasma interaction studies.

In support of the inertial fusion effort, we are devoting considerable resources to target design and fabrication, laser development, target physics experiments, diagnostic development, and system studies. Efforts are underway to determine the feasibility of various types of experiments pertinent to military applications. Potential heavy-ion driver concepts are being explored and the possibilities of incorporating radio-frequency-quadrupole technology in these concepts are being studied.

The Laser Fusion program at Los Alamos is one of the most ambitious projects ever undertaken. It is supported by the Department of Energy, Office of Inertial Fusion, as part of the national energy research effort, and its ultimate purpose is to provide fusion energy for commercial use to help satisfy the nation's future energy requirements.

Roger B. Perkins

Roger B. Perkins
Laser Fusion Program Manager

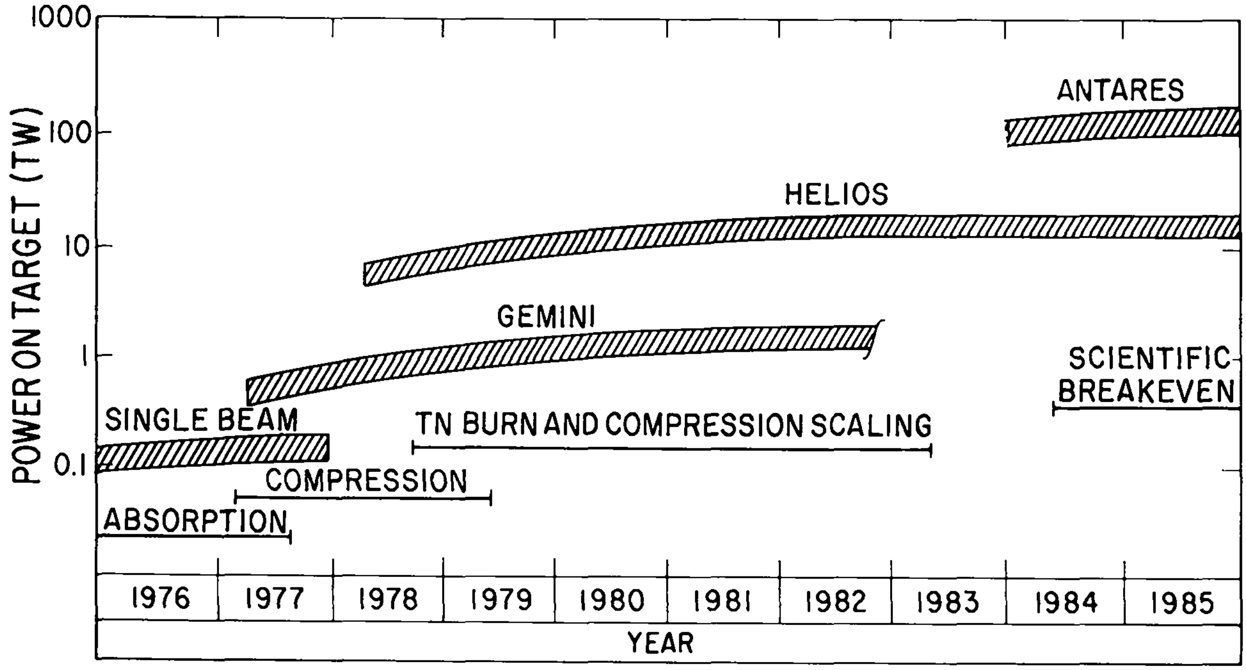
The Laser Fusion Concept

Thermonuclear fusion is the basic energy source of the universe and its stars, including the sun which sustains all life on earth. Fusion occurs when two light elements, subjected to extreme pressures and temperatures, combine to form a heavier element and release energy in the process.

On earth, we are attempting to duplicate the thermonuclear processes of the stars in a controlled fashion by using high-energy lasers to compress and heat to fusion conditions tiny pellets containing heavy isotopes of hydrogen, deuterium and tritium (DT), causing them to release usable energy in the process. One of the key problems in creating fusion reactions on earth, however, is the necessity of attaining fuel densities from 1 000 to 10 000 times the density of normal liquid hydrogen (0.2 g/cm^3) and temperatures up to at least 50 million degrees Celsius, and of confining the resultant plasma long enough for a significant fuel burn. This process is known as inertial-confinement fusion, wherein the DT fuel mixtures are compressed by an imploding spherical container, heated to burn conditions, and then react very fast (in trillionths of a second) before the compressed assembly can fly apart.

To achieve inertial-confinement fusion, an efficient laser like the CO_2 laser must produce very powerful pulses of a few nanoseconds (billionths of a second) duration to compress and heat the fuel. Once the reaction is achieved, the energy it releases is very great — the natural deuterium in 1 gallon of water (1 part in 30 000 by weight), if fully reacted, would produce the energy equivalent of 300 gallons of gasoline.

If the laser fusion program is successful, it will provide a virtually limitless source of energy for mankind. According to our projections this inexhaustible source will become widely accessible within one century.



Los Alamos CO_2 Laser Systems

The research and development programs at LASL on high-energy short-pulse CO_2 lasers were begun in 1969. It was soon realized that the CO_2 laser was the most promising driver for inertial confinement fusion because it uses a cheap gaseous medium that offers significant advantages in efficiency, scalability, and repetitive operation.

The CO_2 gas laser is the most efficient short-pulse laser known; it is also powerful and compact. Gas lasers are ideal for repetitive high-power operation in laser fusion reactors. Unlike glass, gas cannot be damaged irreversibly by a laser beam, and the required cooling is easily attained. In fact, CO_2 lasers have been pulsed repetitively at 750 pulses per second, whereas only 10 to 50 pulses per second will be required for commercial laser fusion.

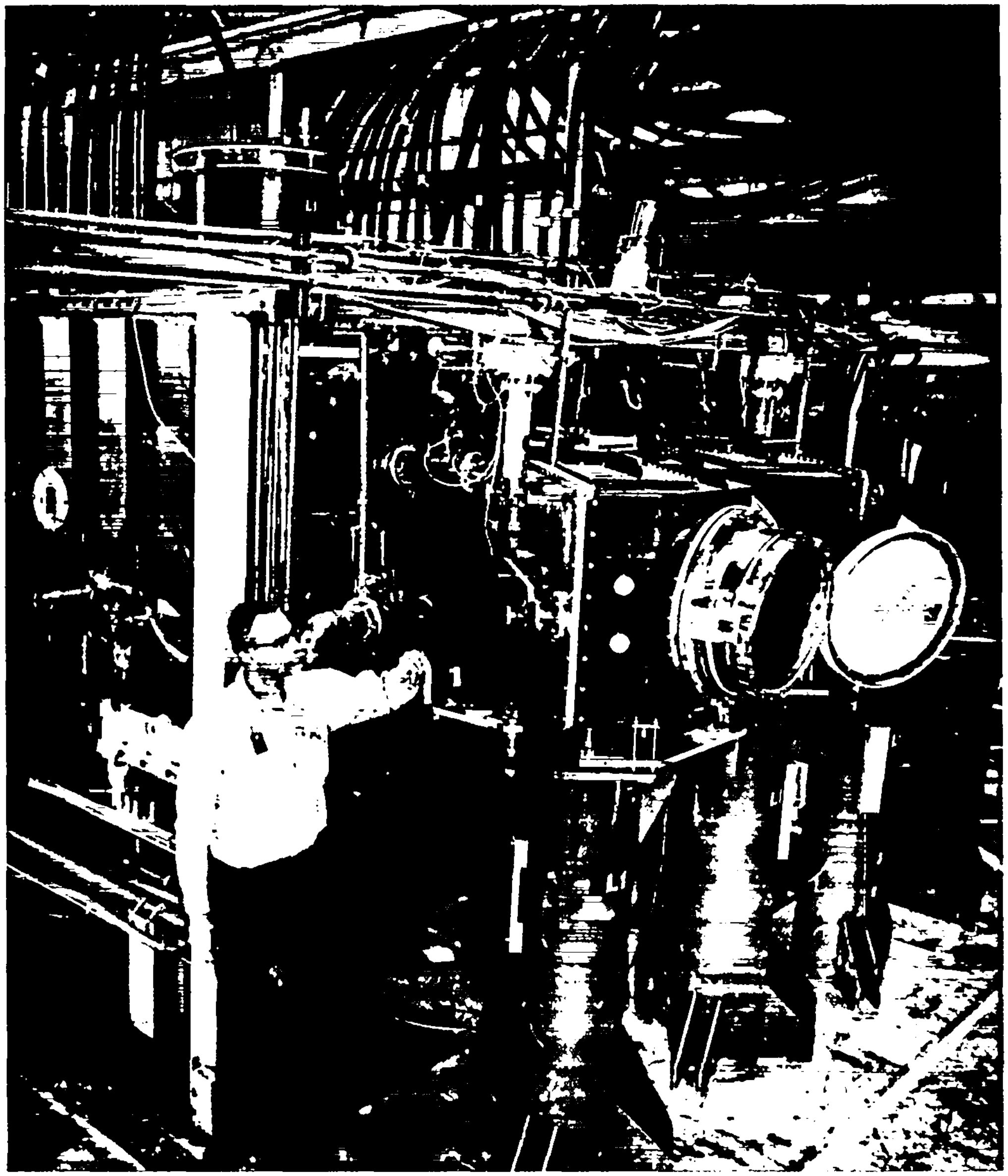
Systems studies of conceptual commercial laser fusion power plants show that CO_2-laser based fusion may be economically feasible, even at today's energy prices which are low compared to those of the future if our energy needs continue to be satisfied by the burning of oil or coal. Major systems studies of laser fusion, at the University of Wisconsin under the auspices of the Electric Power Research Institute, and at the Lebedev Institute in Moscow, for example, base their conceptual designs on CO_2 laser technology.

Single-Beam System

In 1973, LASL began target absorption experiments at the CO_2 wavelength of 10.6 μm with the Single-Beam System and reached energy levels of 100 J in a 1-ns pulse with on-target intensities of 7×10^{14} W/cm^2. This system served as a developmental system for many aspects of operating and controlling high-energy CO_2 laser systems in future experiments. It provided valuable experience that led to the construction of the next-generation laser, Gemini.

Gemini

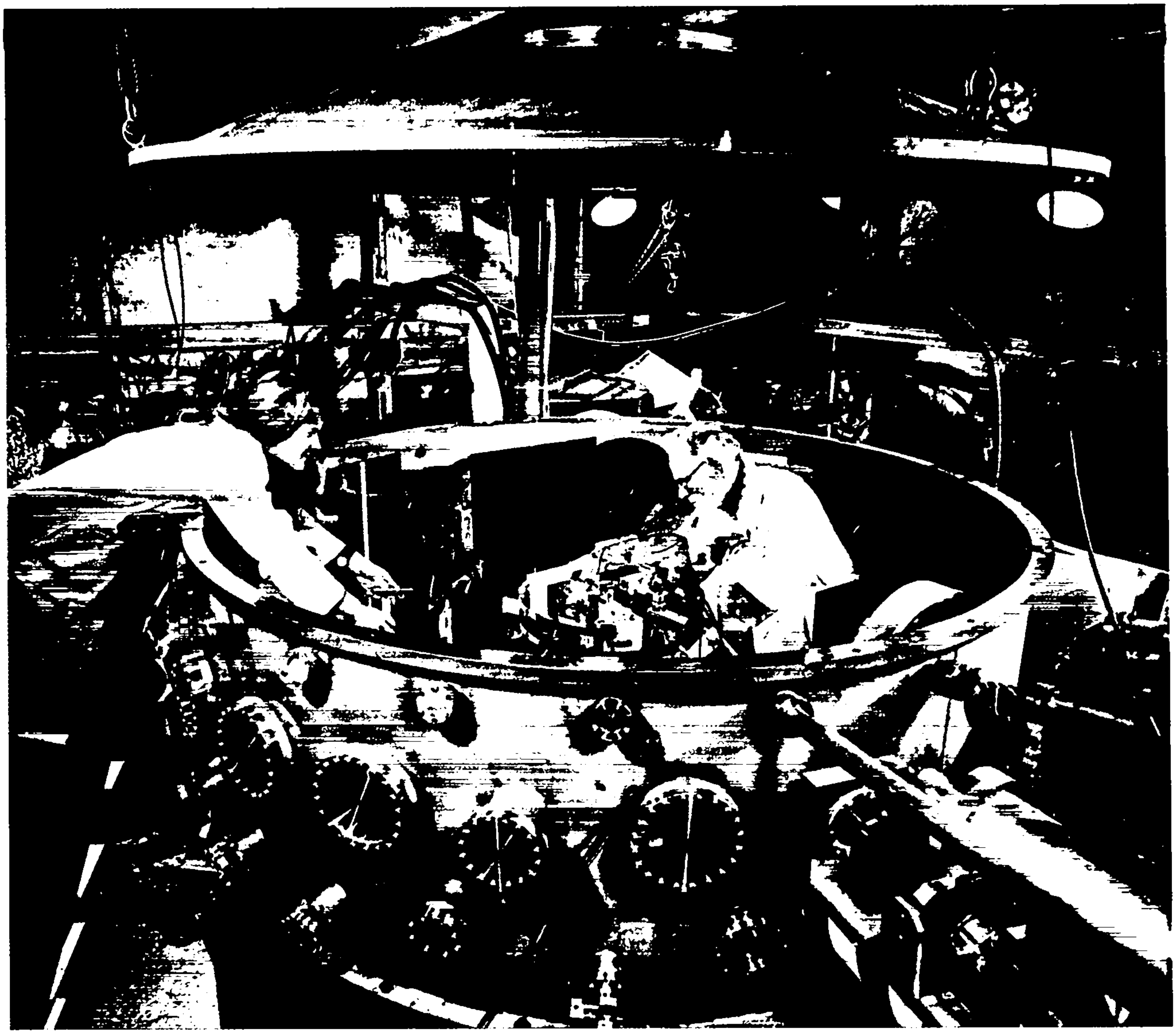
Gemini, a two-beam laser system, became operational in 1976. It was originally intended only as a prototype for a larger eight-beam system. It



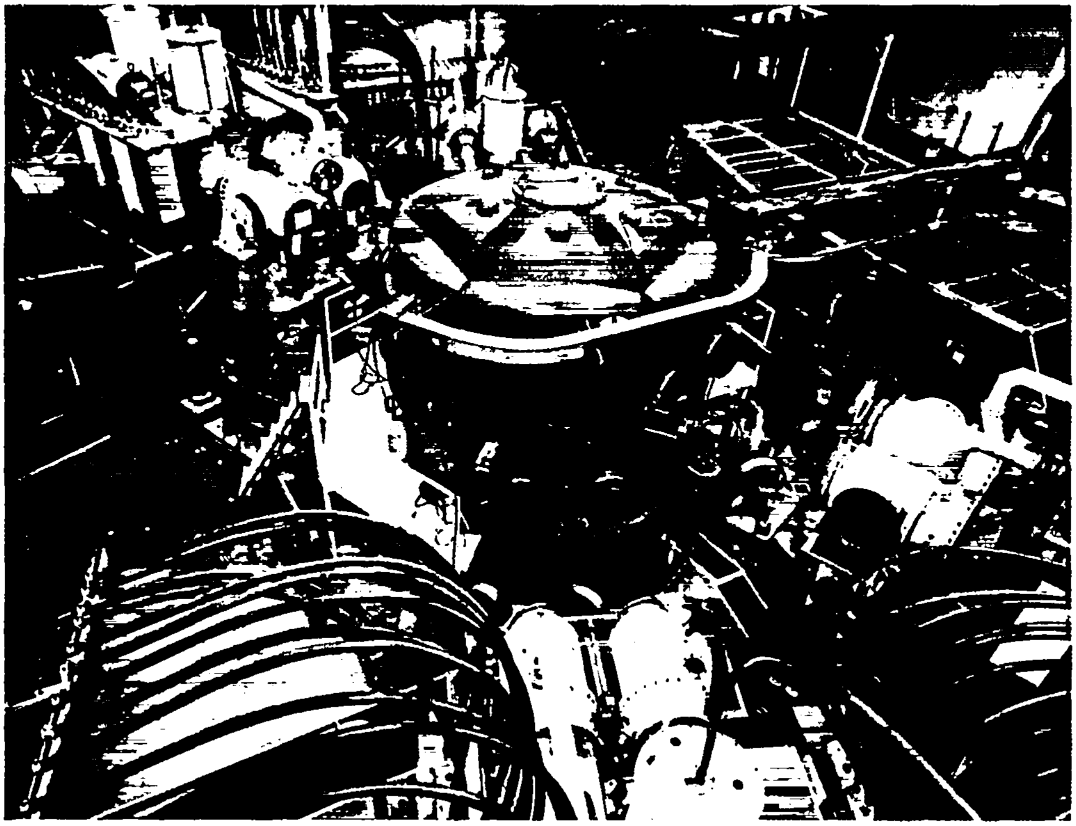
This photograph shows Gemini's twin power amplifier exit ends. Thick polycrystalline salt flats 30 cm in diameter and polished to high optical quality serve as the nearly lossless transmitting windows for each of the nanosecond-pulse laser beams. Master oscillator pulses enter at the rear of the amplifier chambers and after three passes through the 2-m-long carbon-dioxide gain medium, leave through the salt windows.

included two major innovations: first, an electron-beam gun chamber at the center of the machine, which served two amplifier regions, with a significant saving in cost and complexity over earlier amplifiers having only one amplifier region, and second, three-pass amplification, which made the system even more compact — each pulse traversing the amplifier three times, the first two times to provide linear amplification, and the third saturated pass to extract most of the amplifier's energy.

After completion and testing of the new multipass amplifier system, Gemini was used in laser fusion target experiments at energies of up to 0.5 kJ in two beams in 1-ns pulses. In addition to providing a vast increase in technological knowledge about laser and amplifier performance and diagnostics, Gemini made two major contributions to the fusion program. First, early in the national laser fusion program it was thought that the long wavelength of (10.6 μm) CO_2 lasers made these machines unsuitable for fusion. This belief was disproved in various theoretical studies and in experiments with Gemini in 1976 and 1977. Second, the most dramatic contribution was the observation of measurable quantities (3×10^5) of 14-MeV fusion neutrons in January 1977. This was the first time that fusion reactions were ever initiated by a CO_2 laser.



Microscopic laser fusion pellets are mounted at the center of this cylindrical target chamber used for experiments with the Gemini System. When the chamber is evacuated, the two pulsed laser beams are introduced at 150° to each other through twin beam ports (one of which is visible at the center of the photograph). The beams travel past the target, strike focusing mirrors at the opposite sides of the chamber, and then strike the target at intensities greater than 10^{14} W/cm^2. Some of the many diagnostic instrumentation ports in the target chamber wall are visible.



The blue target chamber at the center is surrounded by the four dual-beam modules, each of which produces two laser beams. Design point operation of one beam in the system was attained in early October 1977.

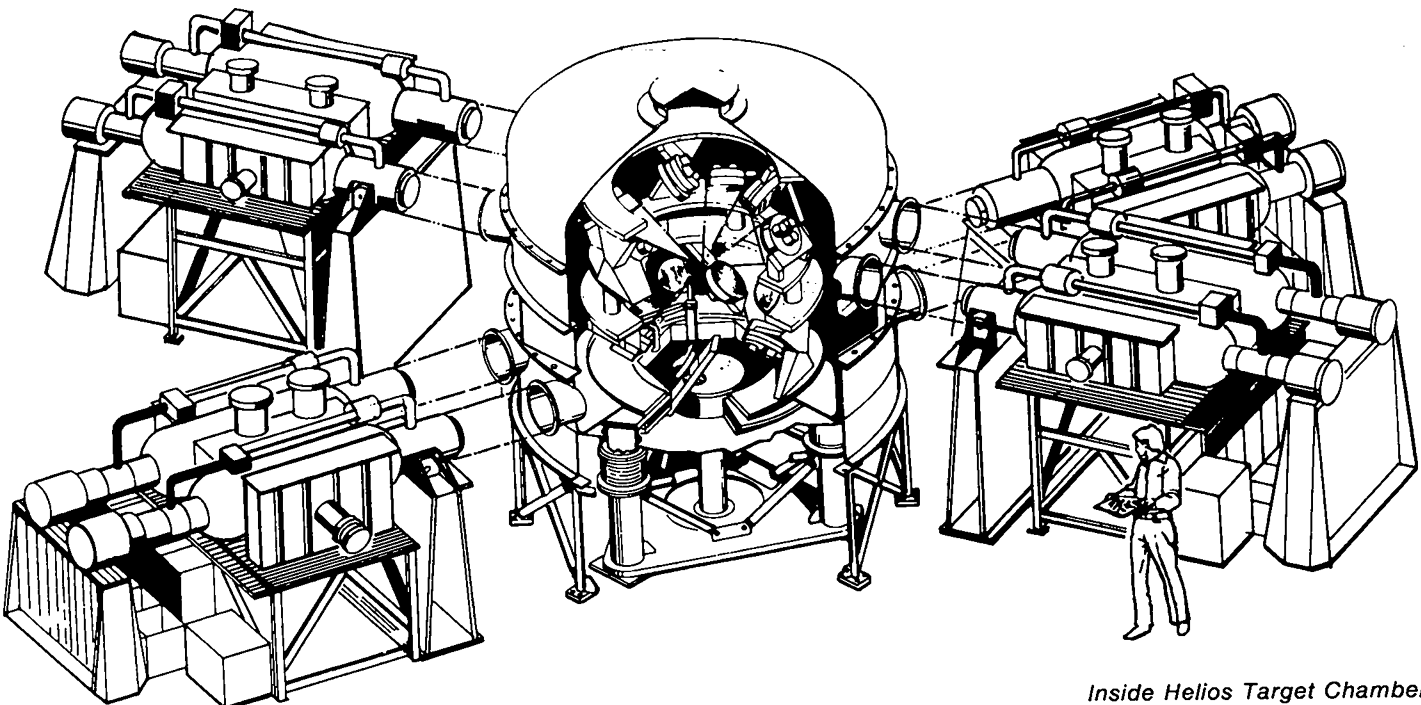
Helios

On the basis of technology developed for Gemini, LASL began construction of the next-generation laser, the 10-kJ, eight-beam Helios system. Helios was completed and successfully tested above design power in April, 1978. It consists of four dual-beam amplifier modules designed to generate eight 35-cm-diameter beams of 1250 J for a total of 10 kJ in a 0.5- to 1-ns pulse with power levels in excess of 20 TW. The Helios targets are positioned at the center of an optical space frame that carries the beam-focusing optics. The entire assembly is enclosed in an evacuated steel target chamber.

This system consists of a set of eight plane mirrors and eight off-axis parabolic focusing mirrors. The mirrors are mounted inside the target chamber (constructed by the Rocketdyne Division of Rockwell International) on a frame that is vibrationally isolated from both the target chamber and the floor. A hydraulic lift is used for placing the heavy optical components inside the chamber. Four pairs of ports admit the eight power-amplifier beams into the target chamber at different heights. They are then focused onto the target through the corners of an imaginary cube whose center coincides with the target. Fusion targets are introduced through a separate port in the side wall of the chamber.

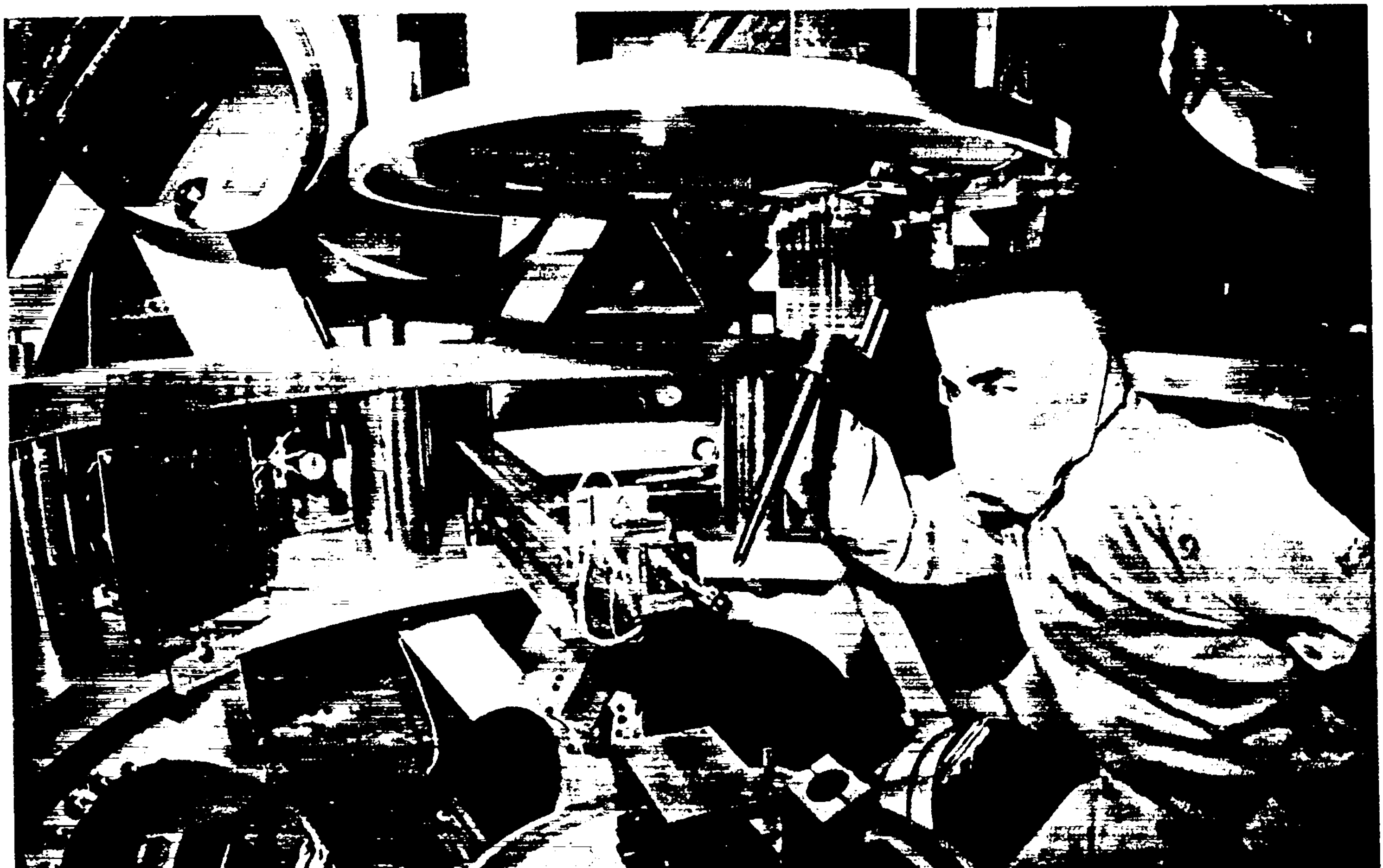
An important innovation in Helios was the addition of a bleachable gas absorber cell inside each amplifier. At low laser light levels typical of parasitic oscillations, this gas cell absorbs the laser light to prevent buildup of the undesirable parasitic oscillations. This absorption does not reduce the beam output energy significantly, because the early portion of the main laser pulse bleaches the gas, making it transparent to the rest of the pulse.

The optimistic energy design goal for the entire system was comfortably exceeded in June 1978 when the system delivered 10 700 J in a subnanosecond pulse. In late 1978 Helios was used to irradiate at DT-gas filled target coated with 54 μm of parylene and demonstrated for the first time that longer implosion times and much higher fuel densities could be achieved. The goals of present Helios target experiments are fuel compressions as high as 20 times liquid-hydrogen density, and development of prototype targets that will allow us to demonstrate scientific breakeven in Antares.



Helios Laser System

Inside Helios Target Chamber - Surrounding the Hartmann ball and target alignment mechanism are eight turning mirrors and the eight focusing mirrors that direct the laser beams to the target.



Artist's conception of Antares laser facility scheduled for completion 1983.

Antares

With the proven success of Helios, the Laser Division at Los Alamos was ready to move to the next generation laser, Antares, ten times more powerful then Helios. This is our "breakeven" laser, the feasibility system that has been in the making since early 1969.

Antares is a $62.5-million construction project that will significantly broaden the scientific and technological base of inertial confinement fusion by achieving the major milestone of scientific breakeven. The massive laser system is scheduled to be complete and ready for experiments in early 1984. Before construction of such a large machine was begun, a prototype was constructed to prove the operating parameters of the new giant amplifiers. Completed in 1977, this prototype amplifier proved the electromechanical design, demonstrated the feasiblity of a radial cold cathode grid-controlled electron-beam gun, and established design limitations imposed by the azimuthal magnetic field and maximum permissible gas pressure. A CO_2 laser gas kinetics code was developed and experimentally

Construction of Antares, LASL's 100 kJ laser system is well under way. Completion of this 62.5-million-dollar facility is scheduled for early 1984.

Salient Antares Features

Energy	**100 kilojoules**
Power Pulse Length	**100 terawatts in 1 ns** **200 terawatts in 0.3 ns**
Laser Gas	**80% CO_2, 20% N_2**
Wavelength	**4 lines in 10 micrometer band**
Number of Annular Beams	**6 (66-in. O.D.x43-in. I.D.)**
Number of Sectors per Annulus	**12**
Pumping Means	**Electron beam controlled discharge**
Discharge Voltage	**550 kilovolts**
Energy Storage	**6 megajoules (7.2 MJ available)**
Focal Spot	**$<$400 micrometer diam.**
Laser Design	**120 man-years**
Laser Installation	**240 man-years**
Cost of Buildings and Facilities	**$11.0 M**
Cost of Laser System	**$51.5 M**
Building and Facilities Completed	**September 1979**
First Annular Beam Tested	**October 1981**
Completed System Tested	**December 1983**

Antares

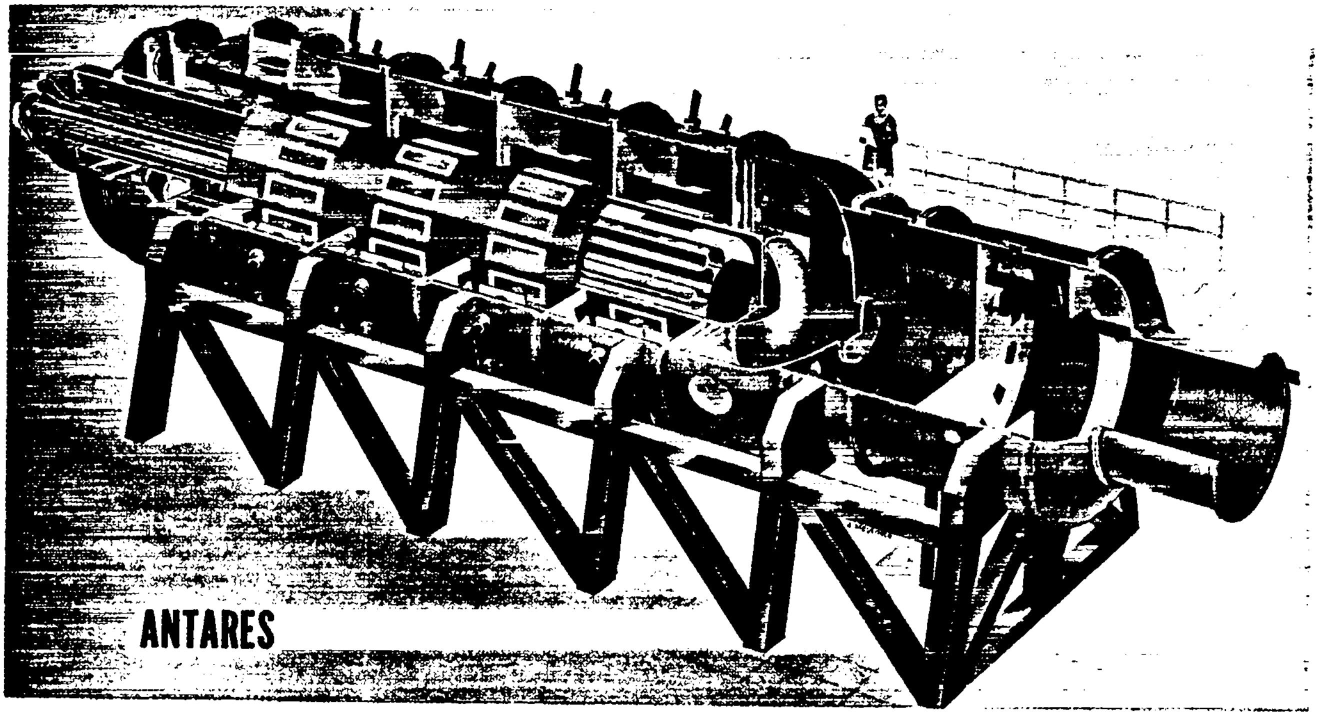
Suppliers & Consultants
March 1979
(Partial List)

Maxwell Laboratories, Inc.	*San Diego, CA*
March Metalfab Inc.	*Hayward, CA*
Burleigh Instruments, Inc.	*Fishers, NY*
Lumonics Research Limited	*Ontario, Canada*
Chromatics, Inc.	*Atlanta, GA*
G.O. Carlson, Inc.	*Thorndale, PA*
Nelson and Johnson	*Boulder, CO*
Zygo Corporation	*Middlefield, CT*
Lukens Steel Co.	*Coatesville, PA*
Hewlett-Packard Co.	*Rockaway, NJ*
	McMinnville, OR
	Colorado Springs, CO
Kirk-Mayer	*Los Angeles, CA*
Ideal Engineering Corp.	*Indianapolis, IN*
Optical Coating Laboratories, Inc.	*Santa Rosa, CA*
Aerotech Inc.	*Pittsburgh, PA*
Harshaw Chemical Co.	*Solon, OH*
Micron Machine Co.	*San Diego, CA*
Union Carbide Corp.	*Oak Ridge, TN*
II-VI Inc.	*Saxonburg, PA*
Digital Equipment Corp.	*Maynard, MA*
Diversified Manufacturing	*Lockport, NY*
Applebay Sailplane Co.	*Rio Rancho, NM*
Leybold-Heraeus Vacuum Products, Inc.	*Monroeville, PA*
Moulded Chemical Products Co., Inc.	*Kirkland, WA*
Canron, Inc.	*Tacoma, WA*
Newport Research Corp.	*Fountain Valley, CA*
Hughes Research Labs	*Malibu Beach, CA*
Systems, Science and Software	*Hayward, CA*
University of Arizona	*Tucson, AZ*
University of Tennessee	*Knoxville, TN*
University of Missouri, Rolla	*Rolla, MO*
Present Total for Outside Firms	*$25 million*

DOE

Engineering & Construction Contracts

Allen M. Campbell Co.	*Tyler, TX*
Pittsburgh-Des Moines Steel Co.	*Pittsburgh, PA*
Norman Engineering Co.	*Los Angeles, CA*
Construction and Engineering Total	*$16.2 million*



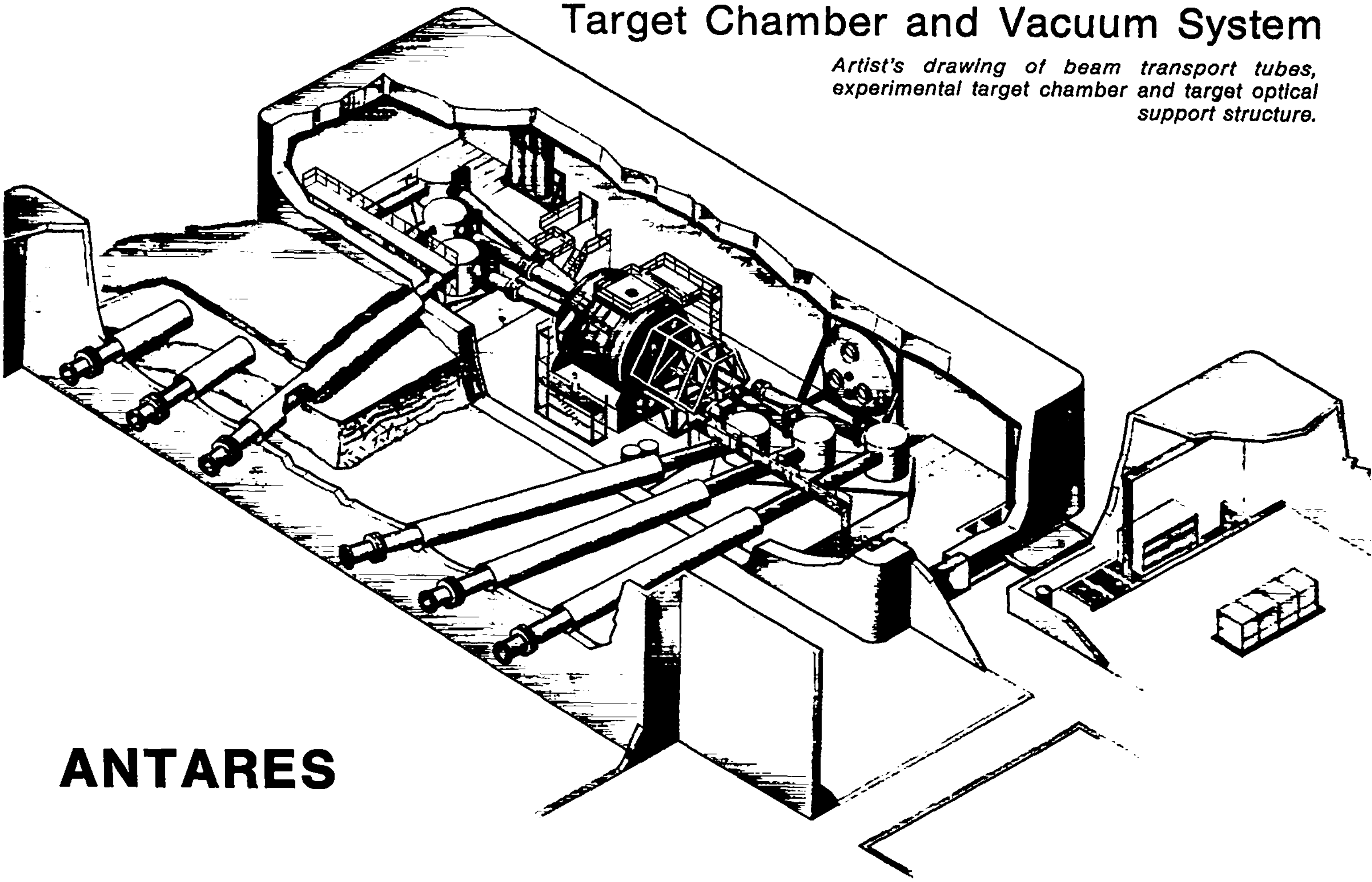
Six of these modules will amplify the laser pulses in Antares. The central cylinder in the module contains an electron-beam source that controls the laser gas electrical discharge. Each module will amplify 12 laser beams, each of which will pass twice through the gain medium. A typical beam path is shown in red.

verified. It was also shown that operation of a large-aperture CO_2 laser is feasible at a discharge voltage of 550 kV. More convenient electron-beam foil structures were tested and withstood the stresses encountered during operation.

The Antares design is based on the technology developed for LASL's Gemini and Helios laser systems. The Antares performance specifications call for an optical output of 100 TW in 1-ns pulses. The optical front end, consisting of oscillators, switchout units, and preamplifier stages, is designed to deliver 30 joules to the input of each of six annular electrically excited power amplifiers. This energy is amplified to the rated output of 17 000 joules per module. The electrical power to excite the 2.5 atm of CO_2:N_2 laser gas mixture to high inversion levels is provided by 24 low-inductance Marx generators. These generators store 300 kJ each, at an open-circuit voltage of 1.2 MV. The 72 high-power beams (12

Target Chamber and Vacuum System

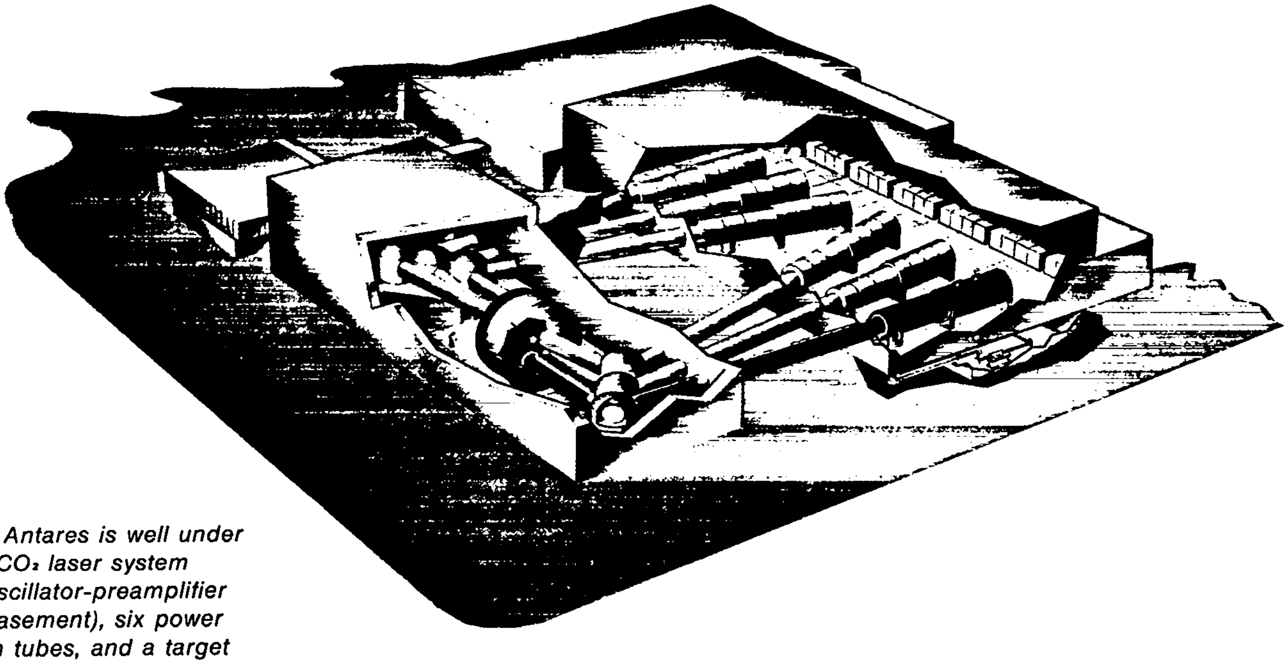
Artist's drawing of beam transport tubes, experimental target chamber and target optical support structure.



ANTARES

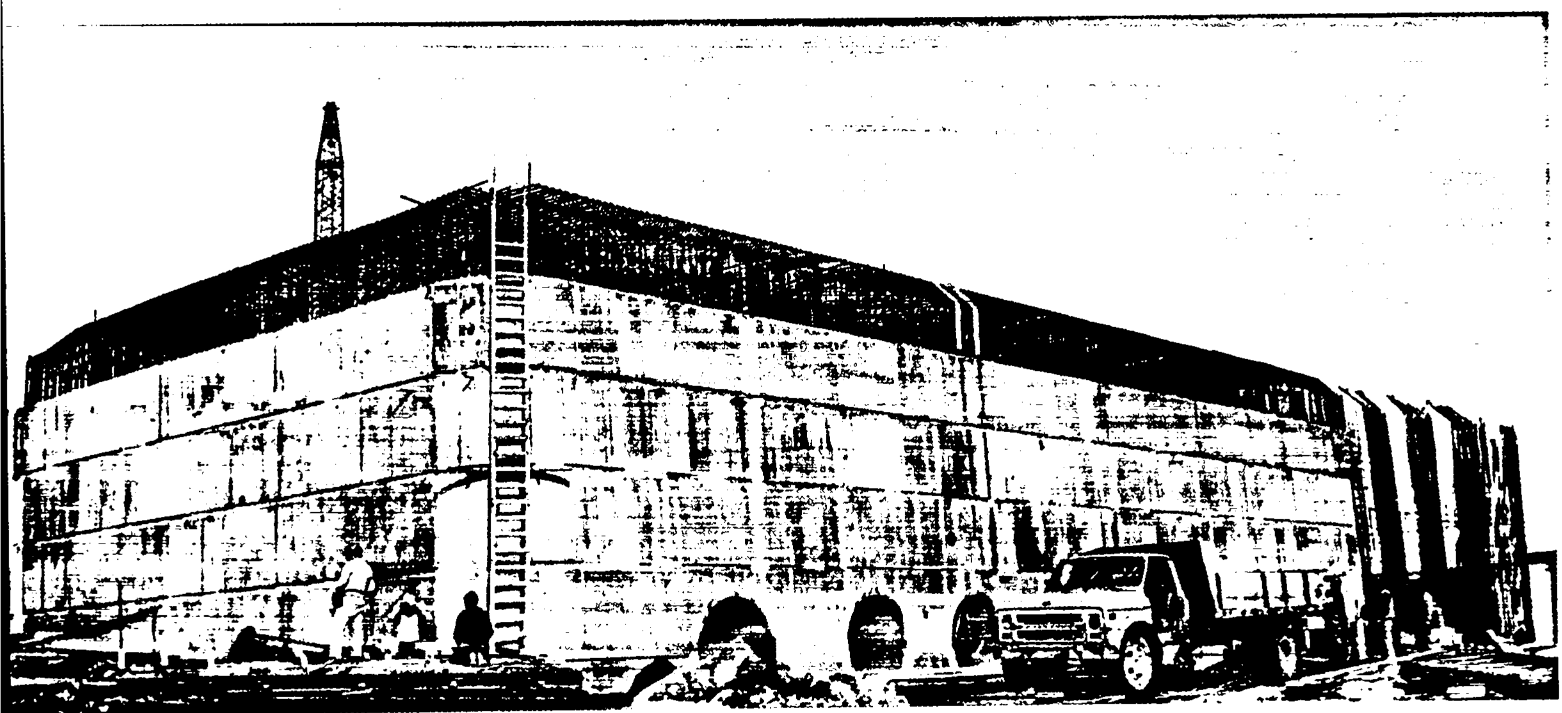
sectors in each of the 6 amplifiers) are transported through evacuated beam tubes from the laser hall to the target building and are then combined in a 7-m-diameter experimental target chamber to uniformly illuminate a focal volume of 400-μm diameter.

Antares will be installed in a 92 000-square-foot facility designed specifically for it. The principal buildings are the laser hall, which contains the lasers and power supplies, and the target building, which is the experimental area. The target building is heavily shielded to prevent escape of the 14-MeV neutrons arising from the fusion reactions. Construction of the buildings began in October 1977 and will be completed in September 1979. Laser-system components are being fabricated so that installation of the first modules can begin upon the buildings' completion. The installation-and-checkout phase will last four years, with target experiments planned to begin in 1984.



Construction on Antares is well under way. This large CO_2 laser system consists of an oscillator-preamplifier subsystem (in basement), six power amplifiers, beam tubes, and a target chamber. Upon completion, the Antares laser system is expected to demonstrate scientific breakeven, fusion yield equal to the laser energy incident on the fuel pellet.

The Antares target building with its massive six-foot-thick walls was near completion in early 1979.



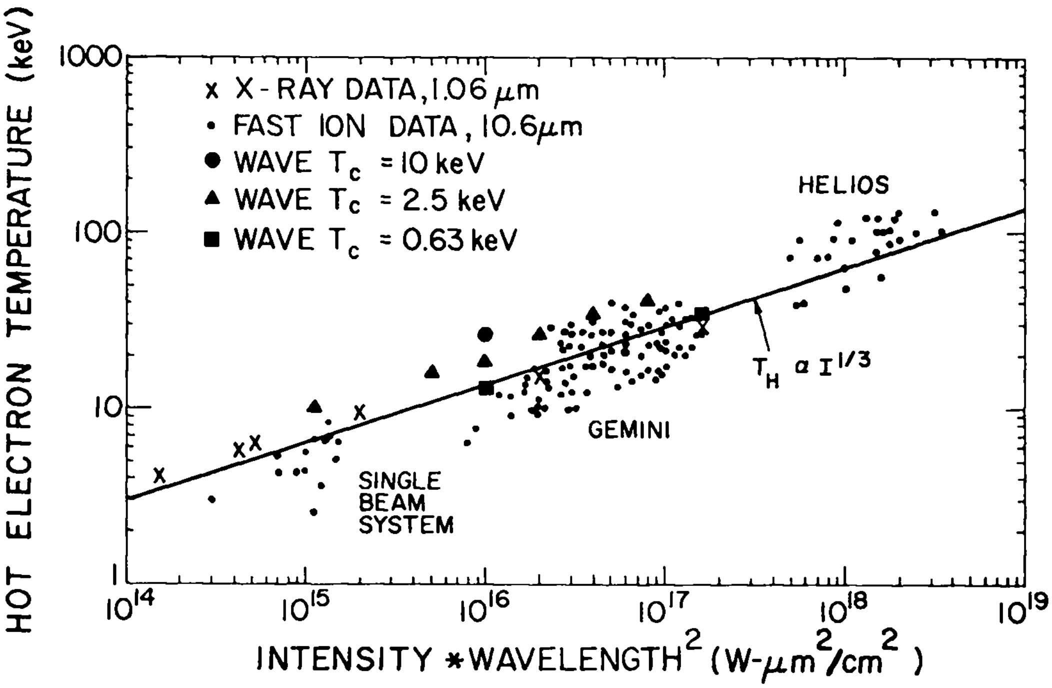
Theory

And Experiments

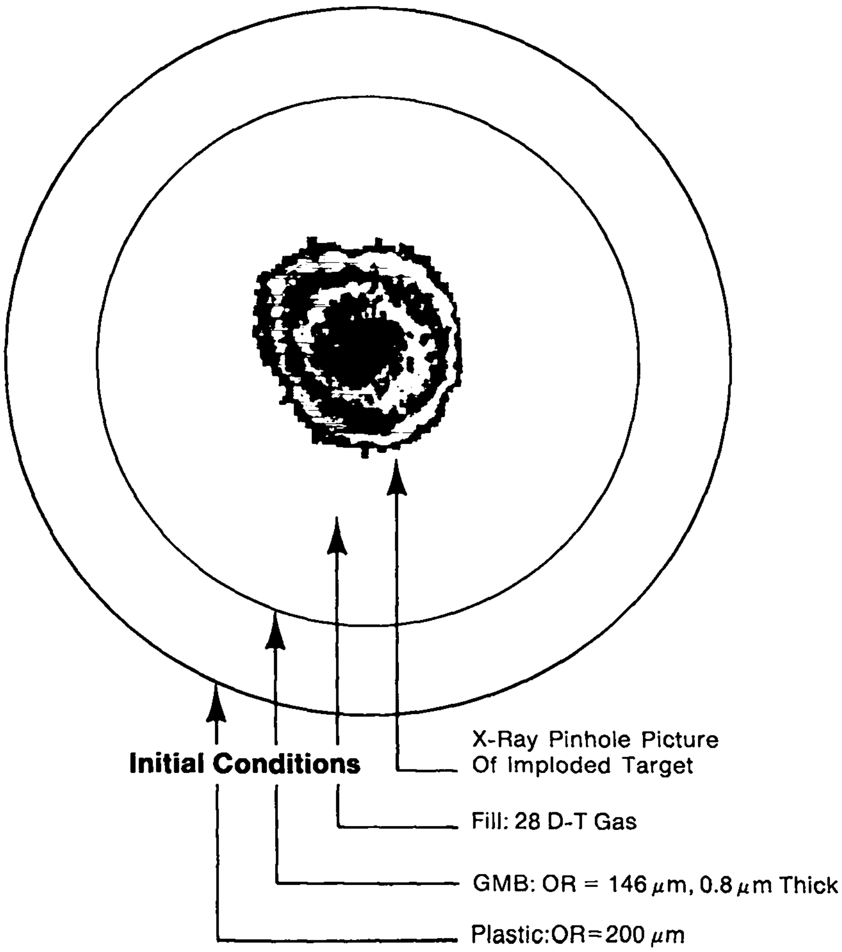
The complex interaction of laser light with fusion pellets must be completely understood. The physics problems encountered constitute an almost completely new scientific field. The phenomena of fusion occur naturally only in the sun and other stars. Therefore, close interaction among the theoreticians, target fabricators, experimentalists, and laser scientists is required to provide an understanding of the underlying physics of fusion phenomena. In the 1970's laser fusion research included experiments with both simple and complex targets, allowing theorists to assess their approximations and assumptions used in their complex computer codes and to guide the development of new models of important physical processes in laser fusion.

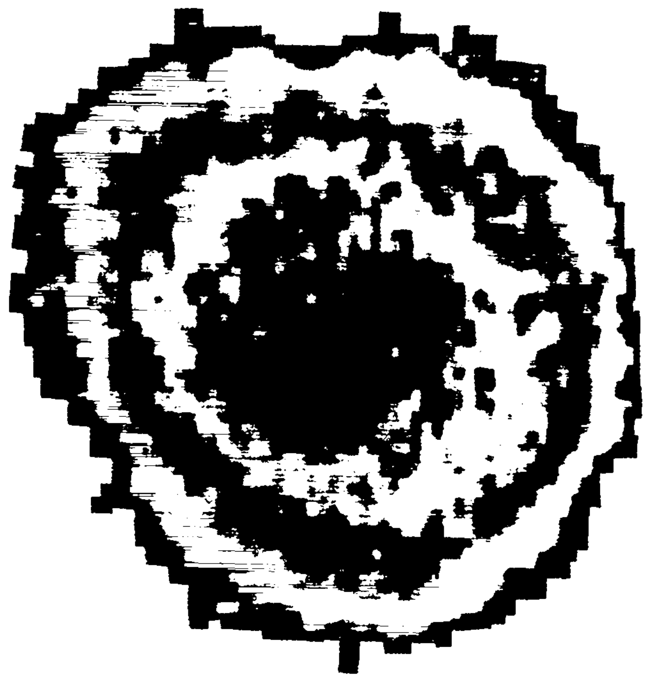
Another essential aspect of this work is the development of instrumentation to diagnose the physical processes that occur in laser-target interaction experiments. The desired experimental observations include the time behavior, quantities, and energies of charged particles (ions and electrons), neutrons, and photons (x rays, visible light, infrared). Important processes may occur in spatial dimensions of a few micrometers and with time durations of a few picoseconds; measurements in such small units require that most diagnostic instruments be specially developed for each application. For example, LASL has developed the fastest detector in existence, an x-ray streak camera. This camera, along with other sophisticated diagnostic equipment developed or used at Los Alamos, helps scientists to understand the laser-target interactions and to design and develop new targets.

One of the major objections raised to the suitability of the CO_2 wavelength for laser fusion involves the generation of hot electrons. The long wavelength implies that the laser light would be absorbed far from the pellet center where the electron density is low. Because of this low density and large density scale length, individual electrons would become very energetic (hot), enabling them to penetrate to the center of the pellet and preheat the fuel, thereby preventing the ideal compression of the fuel and reducing pellet performance. However, both experiments and theoretical calculations show that this effect is quite weak, proportional only to the two-thirds power of the wavelength, and is verified by experiments at 1.06-μm and 10.6-μm wavelengths and by plasma simulations as shown in the upper figure. This relatively weak dependence on wavelength and intensity arise from the ponderomotive force or laser light pressure, which forces the low-density plasma out of the way and allows the laser light to penetrate to a high-density essentially independent of the wavelength. This strong modification of the profile at electron density substantially reduces the hot-electron energy from what would otherwise be expected.



Experimental Results Indicate Weak Wavelength Dependence





3X Enlargement of Imploded Target
Note Good Symmetry.
Volume Compression 250

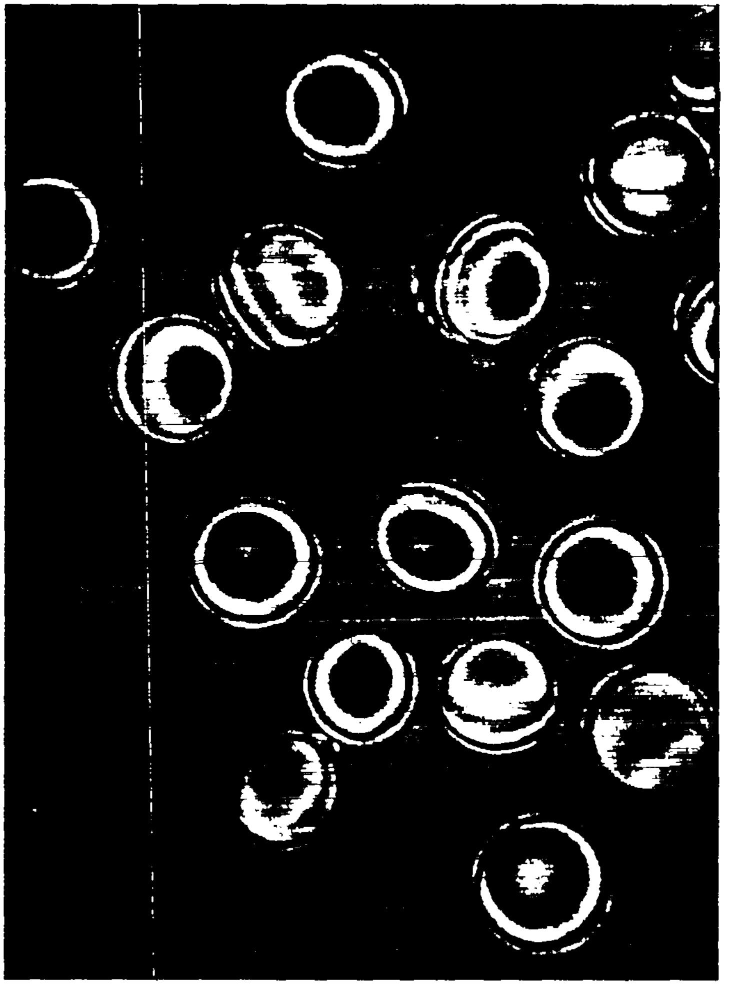
Target Fabrication

Another component of the Laser Fusion program is the fabrication of fusion-fuel-containing targets. These targets are usually submillimeter-diameter hollow spheres of glass or metal (called microballoons), filled with high-pressure DT gas and frequently coated with additional layers, or surrounded by concentric shells of metal and/or plastic to optimize the interaction of the targets with the laser beams. Many 10-μm to 0.1-μm thick planar targets also are made from metals, ceramics, and/or plastics. All are mounted and aligned in appropriate holders for ready installation into the laser target chambers.

Techniques have been developed for cryogenically condensing the DT onto the inside surface of the microballoon container to form a uniform layer of liquid or solid DT fuel. To meet the requirements for advanced, high-yield targets, nearly half of the target fabrication effort is concentrated on developing new ways of coating microballoons with metals and plastics and with metal and plastic foam, on developing micromachining methods, and on developing improved ultrahigh resolution measurement and characterization techniques.

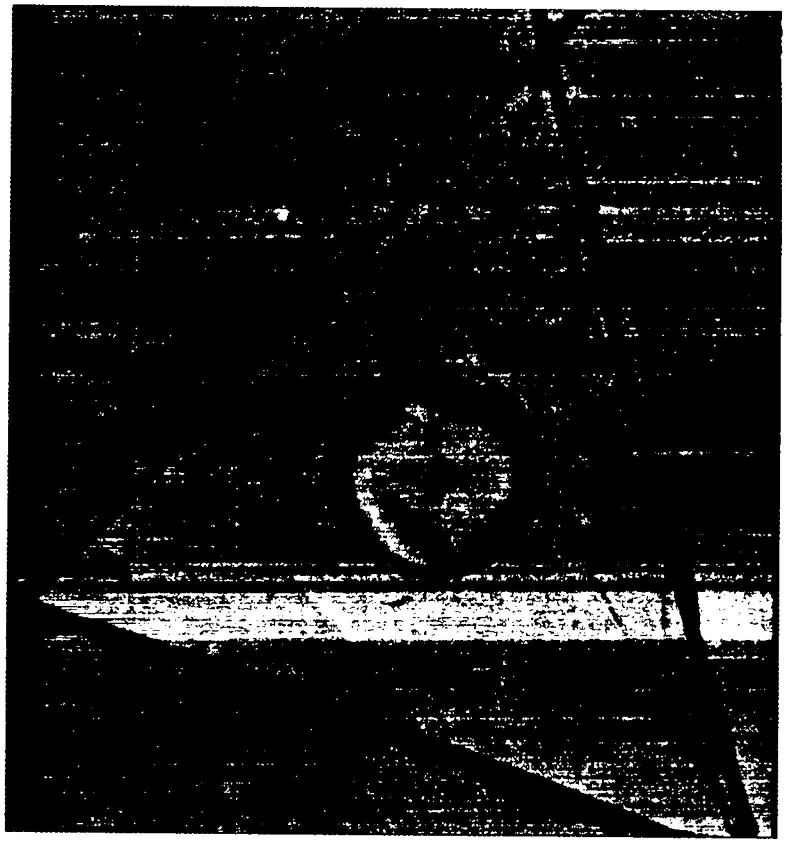
In addition to the laser-fusion targets, targets also are fabricated for the several military-applications experiments that are being carried out by other groups within the Laboratory. These targets range from single- and multiple-layer thin-metal foils for materials properties measurements to hollow plastic shells for blast-wave interaction experiments.

Finally, a wide range of special parts also is fabricated for incorporation in diagnostic apparatus developed at LASL for use in the laser experiments. These parts have included many different single- or multiple-layer metal foils (as thin as 50 nm) for use as selective x-ray filters, small (5-μm-diam) pinholes for x-ray pinhole cameras, and very-small-gauge thermocouples for use in calorimeters, as well as pellicles, beam splitters, and spatial filter apertures for the laser optical systems.

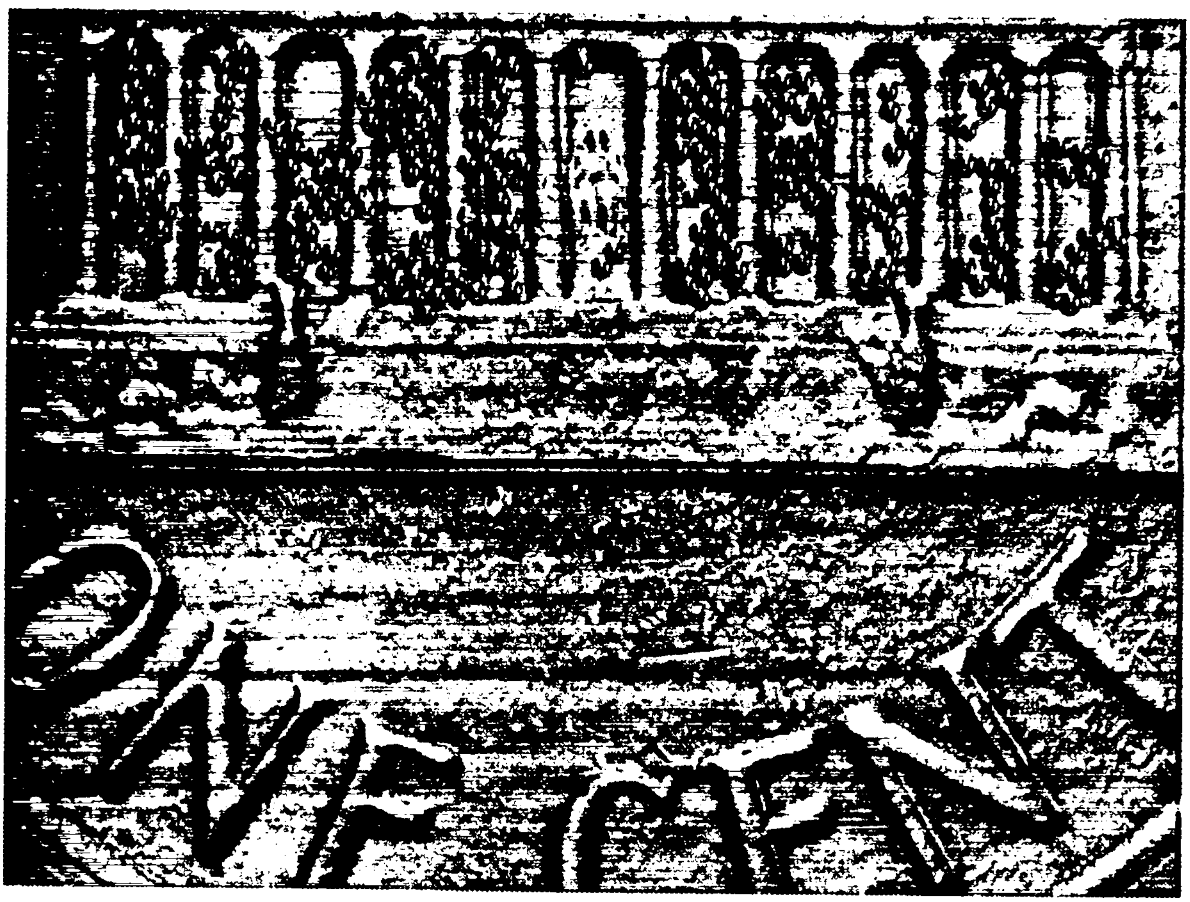


Glass microballoons manufactured for industrial use are typically several tenths of a millimeter in diameter. Only about one commercial glass microballoon in a million has the correct size, wall thickness, wall thickness uniformity, and sphericity required for target experiments in LASL's CO_2 laser systems. After batch processing to remove the grossly inadequate microballoons, an interferogram such as the one in this photograph is made to permit final selection. Only the microballoon at the upper left edge and one in the upper right area have the required wall thickness and uniformity.

Stable support structures that introduce minimal additional material to the volume immediately surrounding the laser-fusion targets are important for precise positioning of the laser beams in experiments with LASL's CO_2 laser systems. One mechanically stable support fabricated from two plastic films and three microscopically small glass fibers crossed to form a triangular frame is shown here. The glass microballoon is sandwiched between the two films, whose thickness is less than one-twentieth the wavelength of visible light.



Tiny gold microshells such as these contain high-pressure (up to 400 atm) gaseous fusion fuel. The laser beams strike the shells causing them to collapse and to compress the fuel. These targets are prepared by electroplating gold onto Solacel (Solar Turbines International, San Diego, CA) metal microballoon mandrels.

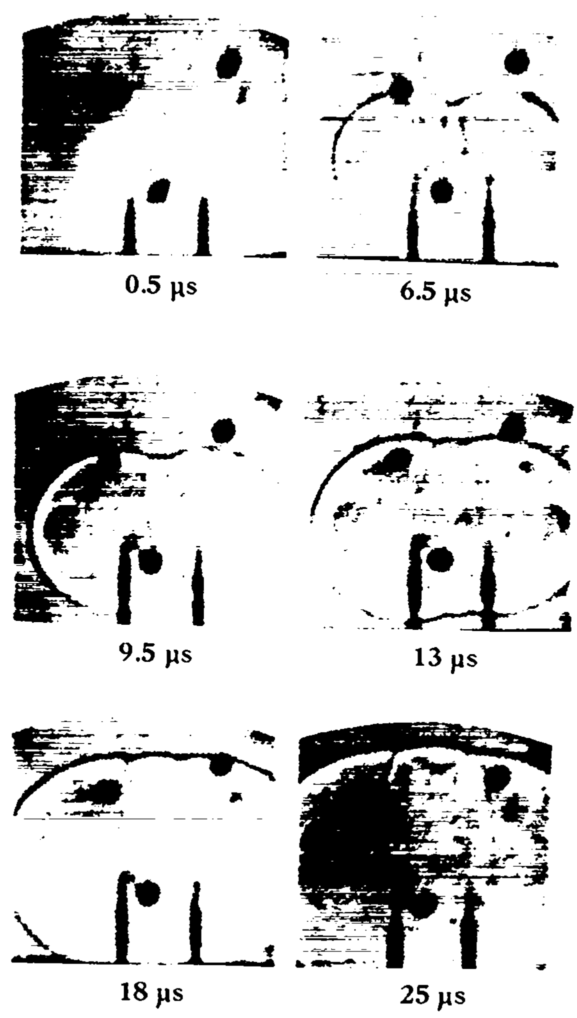


Military Applications

Because designing nuclear weapons is basically an applied science (only a few hundred experiments have been conducted by the United States), there are many areas of uncertainty that can be addressed by laser military applications experiments. These areas include:

Weapons Physics - The basic physics of fusion reactions, including hydrodynamics and other physical effects in nuclear weapons, is imperfectly understood. Laser fusion experiments can make an important contribution to the understanding of these physical processes.

Design Physics — Once breakeven in laser fusion is demonstrated in the Antares system in 1984, it will be possible to expand the contributions to better understanding of weapons physics required for nuclear weapons design. In particular, in the event of a Comprehensive Test Ban Treaty, the Laser Fusion Program and its military applications experiments will provide a laboratory tool for continued studies relevant to retaining our ability to design nuclear weapons.



Simulation of
Multiple Nuclear Bursts

High-Yield Outputs — In laser systems beyond Antares, the very high thermonuclear yields from laser fusion will make it possible to perform important simulation studies of the effects of nuclear weapons.

Experiments with short-pulse lasers have important potential in studies of nuclear weapon's physical phenomena and of weapons effects. An example of importance to the defense community is the effects of simultaneous or near-simultaneous bursts of two or more nuclear weapons. This photograph shows the time development of shock waves emanating from two very small spheres illuminated by a laser. Particularly important are the detailed shock interferences visible at later times. These two microballoons were each irradiated with laser pulses 0.3 ns in duration, containing approximately 30 J of energy. These microballoons were initially separated by 1.8 cm. The energy in each blast wave was approximately 7.5 J. The formation and development of the Mach stem between the expanding blast waves are clearly visible. This two-target experimental arrangement will, in the future, serve as the principal geometry in experiments to validate exisiting hydrodynamic computer models.

Laser Fusion Applications

Feasibility and Systems Studies

The economic and technical feasibility of commercial applications of laser fusion also is being studied in depth. Because electrical power production technology is far better developed than that for synthetic natural gas production or the use of process heat for industrial applications, electrical power generation probably will be the first commercial application of laser fusion. Direct production of electricity by laser fusion in electric generating stations is one major concern that must be studied in great detail.

One objective of these studies is to arrive at a conceptual and preliminary engineering assessment of laser fusion reactors and other generating-station subsystems. The conceptual reactor is highly complex. It was designed to withstand the shocks and debris from laser fusion pellet explosions. The main reaction cavity must provide an appropriate geometry and vacuum so that the focused laser beams can interact with the pellet, and it must be structurally strong to contain the short pellet microexplosion shocks at least once a second. The chamber itself must be constructed of noncorrosive materials to withstand years of exposure to neutrons, ionized particles and x-rays.

The wetted-wall concept, Fig. 1, uses a thin film of liquid lithium on the inside wall of the chamber to protect structural components from pellet debris. Lithium within the blanket produces tritium for the fuel pellets by neutron-lithium reactions and acts as a heat transfer medium to power the steam-generating system. This concept remains a leading candidate for application to commercial laser fusion power plants.

Another reactor concept, Fig. 2, uses a magnetic field to deflect energetic charged particles away from the chamber walls. The cylindrically symmetric reactor first wall is protected by an axial magnetic field produced by a solenoid located concentric with and external to a blanket of liquid lithium that circulates in the outer plenum of the chamber. The magnetic field diverts ionized pellet debris to twin cooled conical energy sinks at either end of the reactor cavity. Provision is made to replace the energy sinks periodically, when radiation and material damage levels exceed operating tolerances. These sinks are made of refractory materials such as graphite. Liquid lithium serves as the wall coolant, as the transport medium for carrying fusion energy to a steam heat exchanger, and as fertile material for producing tritium replacement fuel. Transport tubes for introducing fusion-initiating laser beams are shown entering the reactor cavity. Either a vacuum or a low-density background gas is maintained in the cavity.

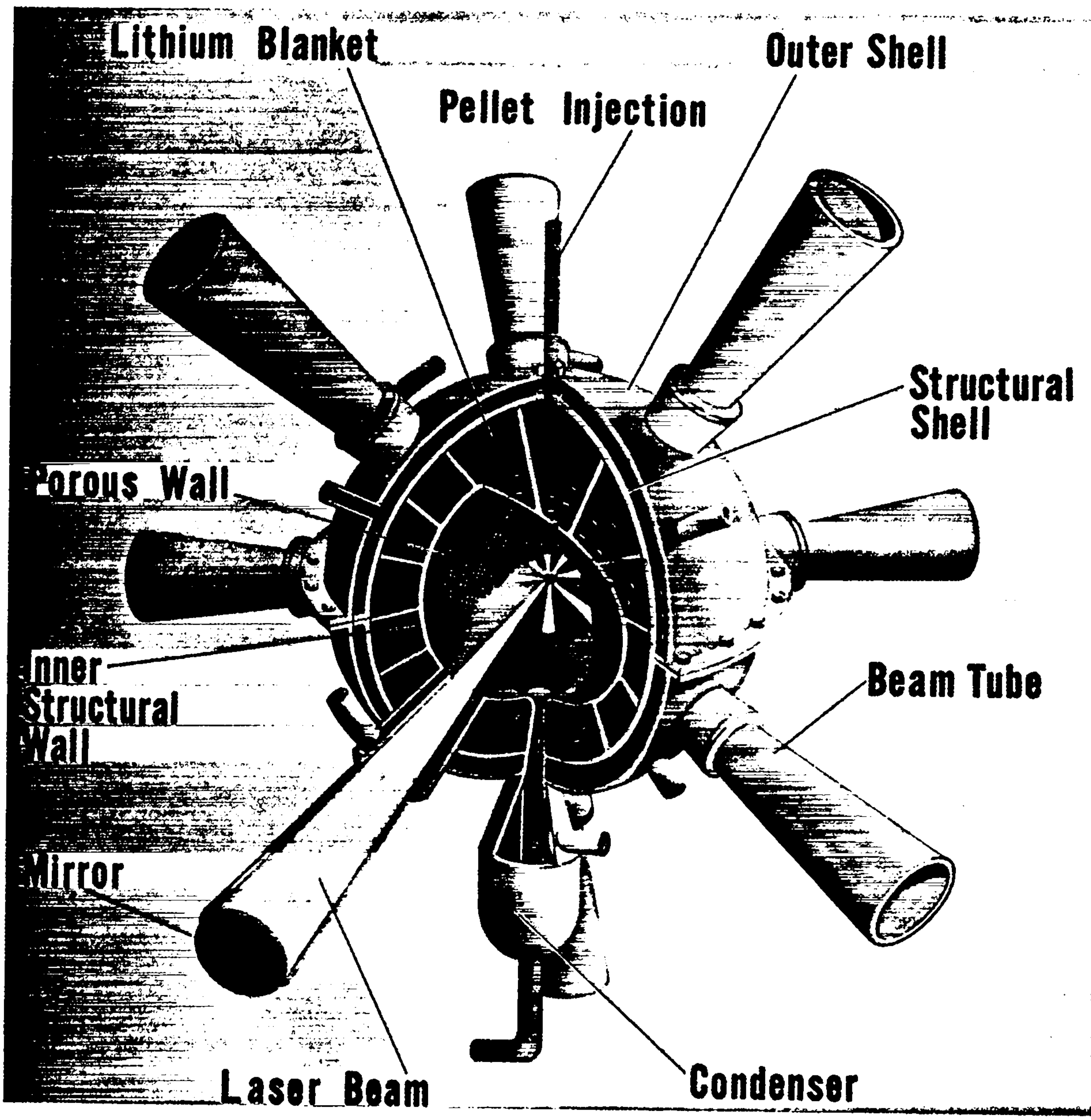
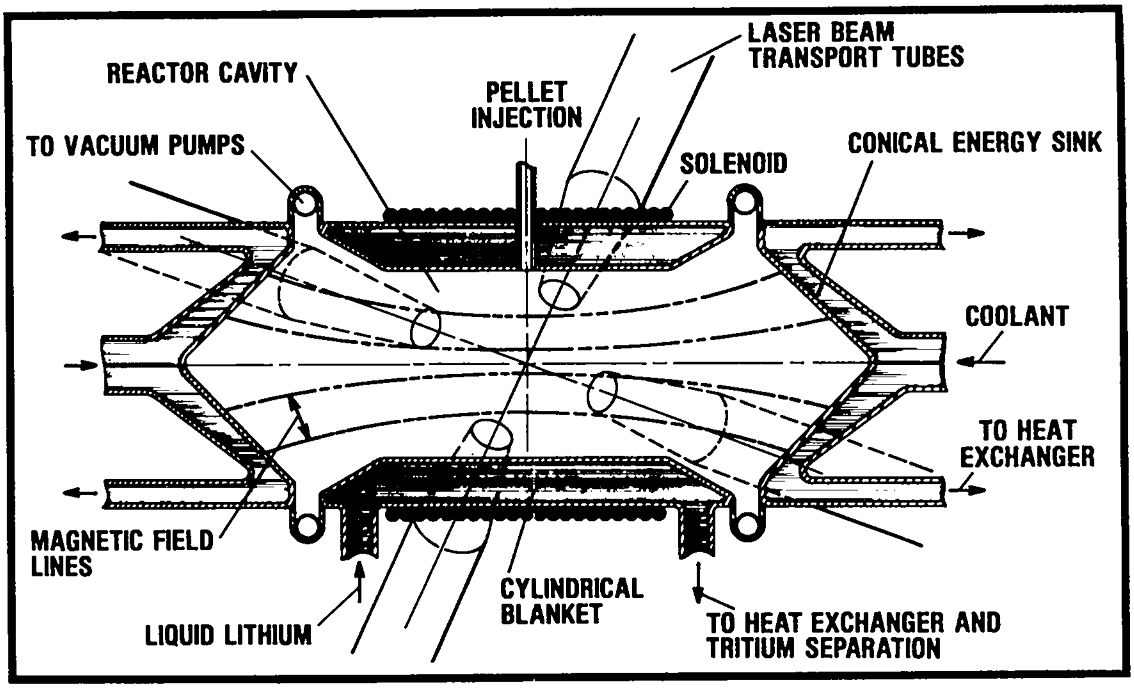


FIG. 1 — Wetted-wall reactor cavity concept.

FIG. 2 — Magnetically protected reactor chamber.



A new concept under study (Fig. 3) is designed to provide process heat at temperatures 1500K > (~2250°F). The reaction cavity is surrounded by a "pool" of boiling lithium which is heated by absorption of high-energy neutrons. Lithium vapor passes from the top of the blanket cavity to a process heat exchanger by natural convection where it condenses on the outside of process tubes, giving up latent heat, then flows by gravity back into the blanket as a liquid. Thus, no pumping is required and the system operates at essentially constant temperature. The structure is kept cool by internal insulation which is protected from corrosion by a liner of refractory metal. Structural stresses are minimized because operating pressures are near atmospheric pressure (at 1 atmosphere, lithium boils at 1645K). Process fluid inside the heat exchanger tubes can be a superheated working fluid for an electric power cycle operating at high efficiencies or a high-temperature decomposition in a thermochemical cycle producing hydrogen as a synthetic fuel.

Another objective of the systems studies is to develop computer models of generating-station subsystems and to identify problems that require long-term development efforts. One way to identify these problems is to design and study conceptual power generating stations. One conceptual design, shown in Fig. 4, involves four reactor chambers (two shown in cutaway), each pulsed ten times per second, whose walls are cooled by molten lithium and protected from fast charged particles by deflecting magnetic fields. There are also four heat-exchanger loops in which heat is extracted from the lithium to produce steam to drive power turbines (the three green objects) whose electric power output is distributed from the adjacent switchyard.

Eight CO_2 laser amplifiers and eight spares (blue objects on the third floor) are driven sequentially by a laser master oscillator located on the top floor. These amplifiers deliver eight 1-MJ, 1-ns pulses 40 times per second through beam tubes (yellow objects) to a rotating mirror that distributes the single pulses to the four reactor chambers in succession.

The identification and eventual solutions of these long-term problems will be instrumental in providing laser fusion electric power plants in the 21st century.

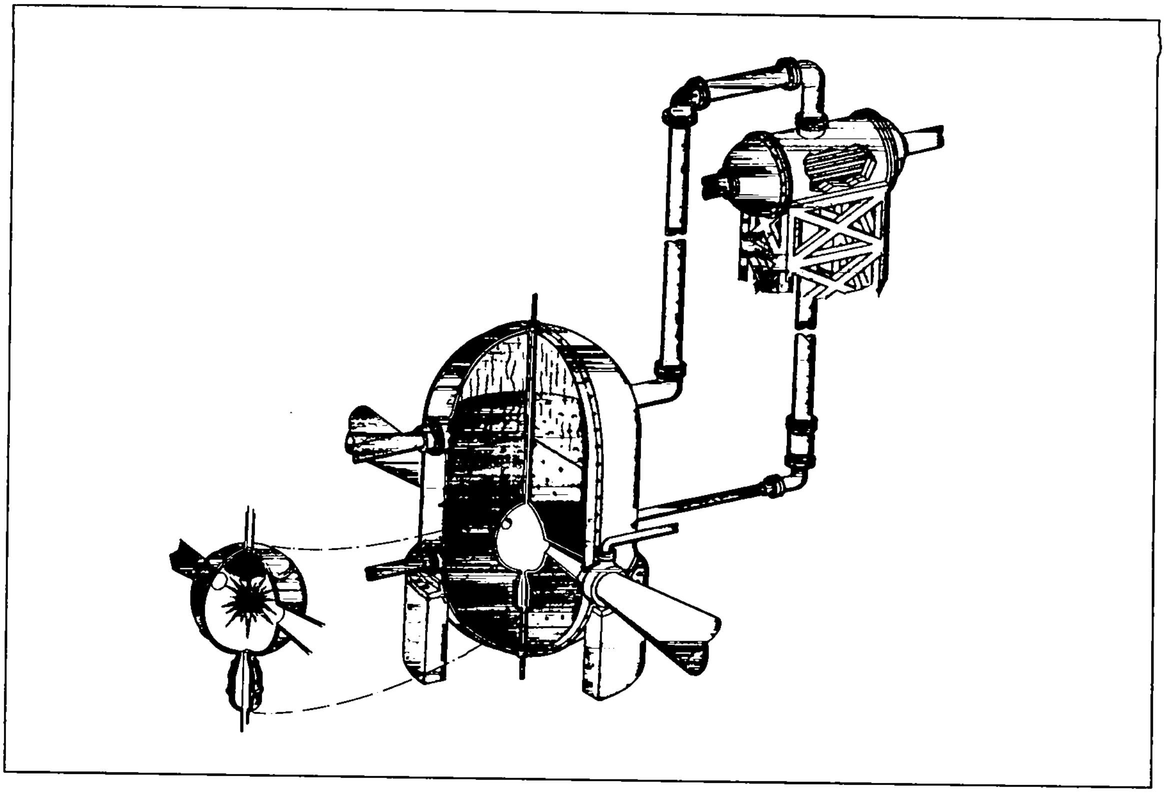


FIG. 3 — Lithium Boiler Concept

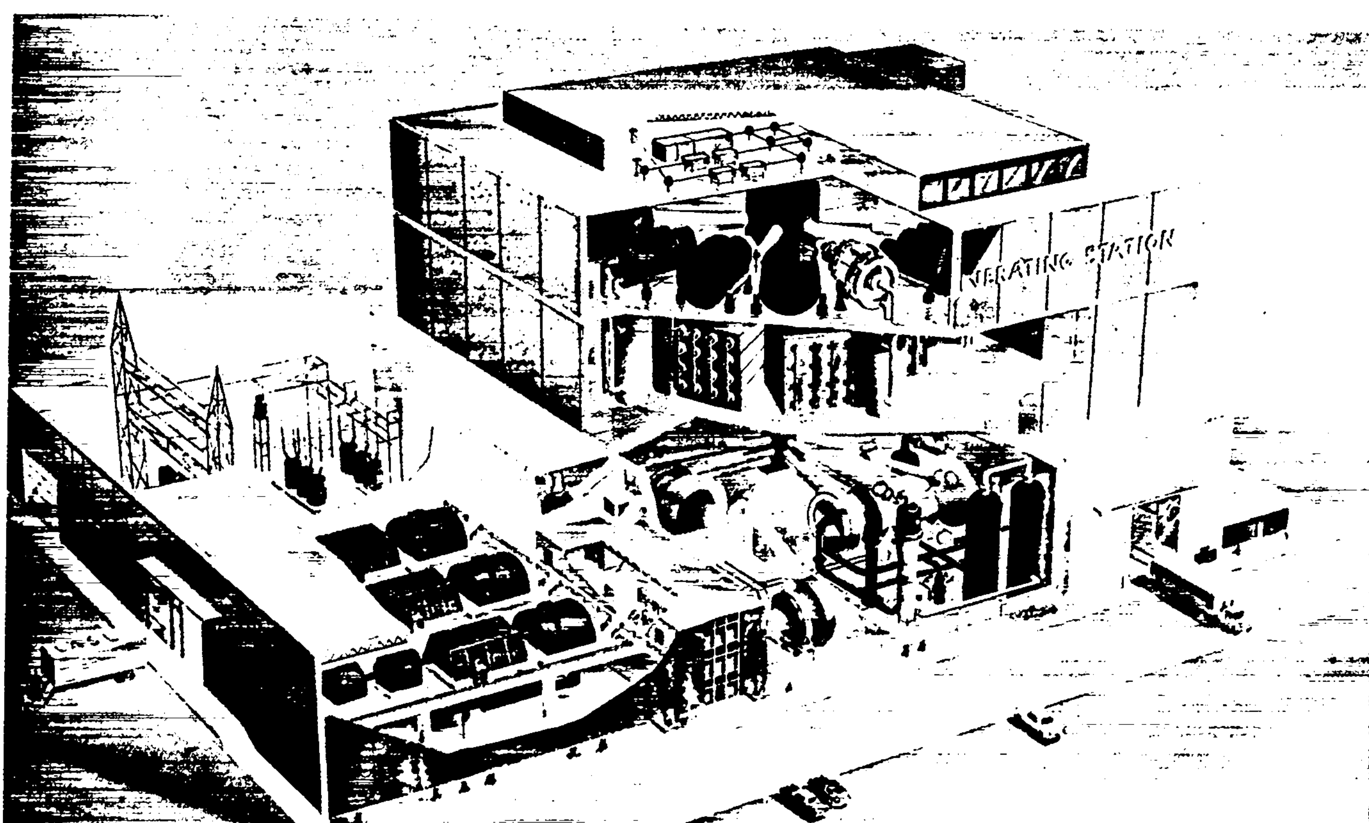
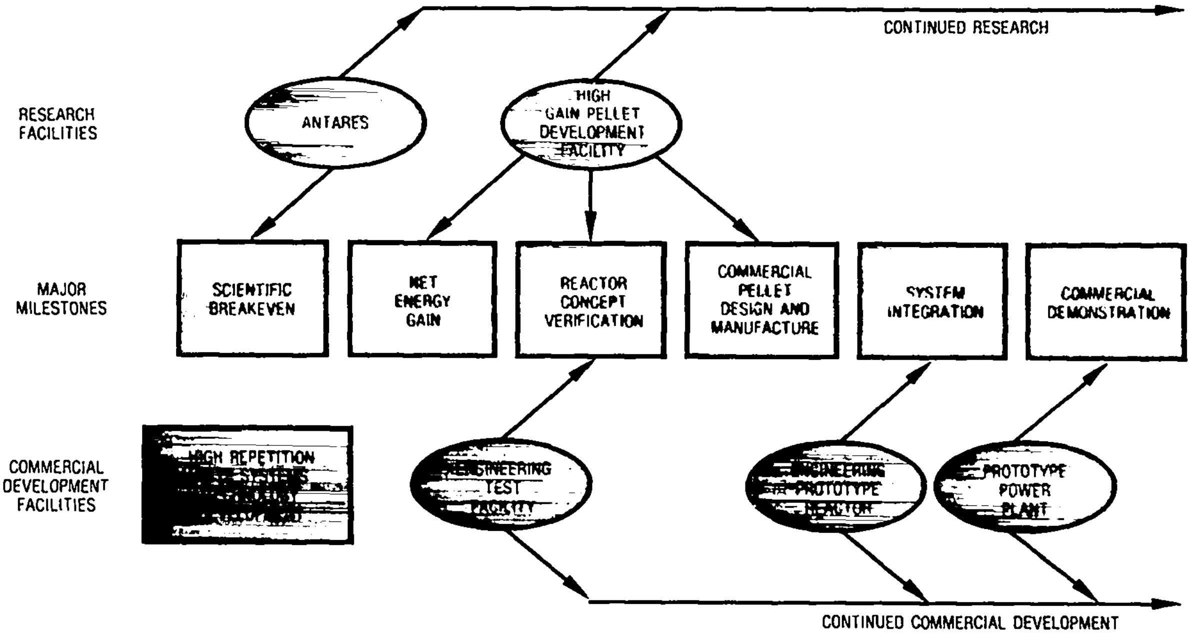


FIG. 4 — Laser fusion power generating station.

Commercial Demonstration of Inertial Confinement Fusion



Program Plan

The sequence of major facilities and milestones included in the LASL program plan for developing inertial confinement fusion to the commercial power plant demonstration stage is shown above. The program has three major phases: technical feasibility, systems development and integration, and demonstration.

Technical Feasibility

The National Laser Fusion Program is now pursuing research along parallel paths to develop several types of drivers to ensure a reasonable probability of ultimate success. The most promising laser at this time, in terms of satisfying all the requirements of commercial laser fusion power plants, is the short-pulse CO_2 laser. The development of high-energy, short-pulse CO_2 lasers has progressed through the design and construction of a series of successively larger systems at LASL with construction now under way on the 100-kJ Antares system, which is expected to demonstrate scientific breakeven. Following successful experiments with Antares, construction will begin on the largest laser, the High-Gain Pellet Development Facility (HPDF). The first major milestone of this facility will be to demonstrate net energy gain, where the fusion pellet energy release exceeds the total energy required to operate the laser.

Systems Development

The development of high-repetition-rate, long-life systems, including driver and pellet injection, tracking and beam-transport systems, as well as reactor and blanket concepts, will require early analytical and experimental investigation.

The first major facility to include high-repetition-rate capability, the Engineering Test Facility, will be designed for proof testing one or more reactor concepts in realistic pellet-microexplosion environments for accomplishing the Reactor Concept Verification milestone. The Experimental Power Reactor will comprise the first complete System Integration of all the subsystems for a power plant. It will demonstrate the engineering feasibility of the entire plant cycle.

Demonstration

The Prototype Power Plant (PPP) will demonstrate electric power production in a reliable, efficient, maintainable system which is licensed and operating on a utility grid. The PPP is the culminating facility of the demonstration phase of the development of inertial confinement fusion technology and will mark the transition from a federally dominated program to a program which is supported and funded by industry and the utilities. Because laser fusion will ultimately be commercialized by industry, it is expected that the later facilities will be designed and constructed by industry.

Further Reading Suggestions

(All available from the Laser Fusion Public Relations Office, Los Alamos Scientific Laboratory, Los Alamos, New Mexico 87545)

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For information on employment possibilities with the LASL Laser Fusion Program please write to, or send complete resume to:

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