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# Overview of Laser Fusion

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## INTRODUCTION

The Laser Fusion Program at the Los Alamos Scientific Laboratory is exploring the use of lasers to fuse atomic nuclei in a controlled manner to release energy. This potential energy source is under intense study in many countries, evidence of its widely recognized promise for mankind. In the United States, laser fusion efforts are supported by the Department of Energy, comprising a partnership of universities, industry, and government laboratories. The National Laser Fusion Program is pursuing an orderly sequence of technical steps that will lead to ultimate commercial application and nearer-term military application of laser fusion energy.

## THE ENERGY OF THE STARS

The sun is our oldest source of energy, the very mainstay of life on earth. The energy of the sun and other stars is produced by thermonuclear fusion, wherein two light elements collide, fuse to form a heavier element, and release energy in the process.

The fusion reaction that is most easily reproduced on earth involves deuterium (D), a heavy isotope of hydrogen found naturally in water, and tritium (T), a rare isotope of hydrogen:

$$\text{Deuterium} + \text{Tritium} \rightarrow \text{Helium} + \text{Neutron} + \text{Energy}\ .$$

The energy released by the reaction is very large—the natural deuterium in 1 gallon of water (1 part in 30 000, by weight) can react to produce the energy equivalent of 300 gallons of gasoline.

Commensurate with the vast potential for fusion energy are the immense scientific and engineering difficulties of harnessing this energy source. The key problem is that the deuterium-tritium (DT) gas mixture must be heated to at least 50 million degrees Celsius and held together long enough for the reaction to proceed. At this temperature, any physical material confining the gases will disintegrate or will cool the gases, quenching the reaction.

There are only three approaches to confining these hot gases:

- Gravitational confinement. Because of their large masses, the sun and other stars are able to hold hot gases together.
- Magnetic confinement. Magnetic fields are used to "bottle up" the hot electrically charged gas atoms (under continuous study worldwide for the last 25 years).
- Inertial confinement. In laser fusion, DT mixtures are compressed and heated very quickly, so that the fusion reactions are completed before the gases can fly apart.

## LASER FUSION

The basic idea of laser fusion power generation is to manufacture a small (less than 1 millimeter* in diameter, which is about the thickness of a dime) sphere containing a DT mixture and to illuminate this fuel pellet uniformly

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*One millimeter equals a thousandth of a meter, or ~0.04 inch.

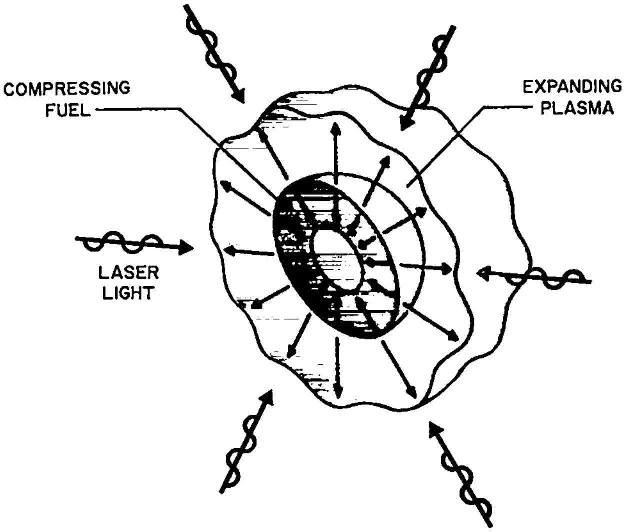

*Fig. 1.*

with a short pulse of laser light, which compresses and heats it very quickly. The process is shown schematically in Fig. 1. The pulse of laser light, only 1 nanosecond* long, strikes the fuel pellet and is absorbed by the outer layer. This absorbed light causes the outer layer to vaporize and blow away as a hot plasma (ionized gas), creating an inward rocket-reaction force in the remaining fuel. This force compresses the fuel in the center of the pellet and heats it to the fusion reaction temperature. The DT fuel undergoes fusion burn, ejecting energetic neutrons and helium nuclei over a time interval of only 10 to 20 picoseconds.**

In order to generate power, the energy released by the fusion reactions will be converted to heat to produce steam for conventional turbine generation of electricity. Laser fusion power may also be used to produce hydrogen from water, and then the hydrogen can be used to manufacture synthetic natural gas. The tritium for the pellets can be produced easily, as part of the heat-generation cycle, by the interaction of fusion-generated neutrons with lithium, an abundant metal.

## REQUIREMENTS FOR LASER FUSION

A schematic diagram of the subsystems of a commercial laser fusion power facility of the 21st century is shown in Fig. 2. The laser system must efficiently convert electricity into laser light, which can be focused upon inexpensive, precisely manufactured fuel pellets. This interaction will occur in a reaction chamber designed to capture all the reaction energy, producing tritium for the pellets and heat for conversion to electricity. Each laser pulse could contain, for example, 1 megajoule† of energy, enough to run a color television set for an hour. Studies of the cost and operation of such a system conclude that the laser system should burn 10 to 50 pellets per second and that each pellet reaction should release 100 times the laser energy, or 100 megajoules in this example.

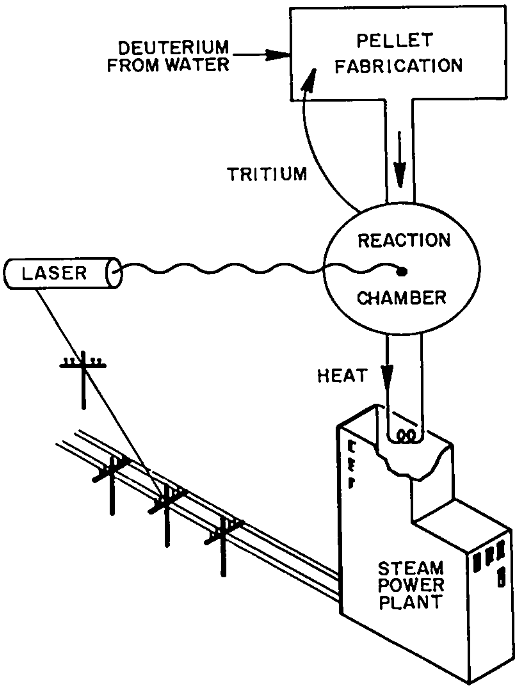

*Fig. 2.*

### Laser Research

Lasers can be made using many different substances, but a gaseous laser will be ideal for laser fusion because gas can be circulated and cooled and cannot be damaged by intense light pulses. Gas lasers are ideal for the fast repetition-rate requirement of laser fusion and are the most efficient lasers known.

Most laser fusion researchers have used the short-pulse neodymium-glass (Nd:glass) laser because the technology is further advanced than that for gas lasers. However, Nd:glass lasers are only 0.1% efficient and can operate at most only once every 10 minutes because of glass heating.

The carbon dioxide ($CO_2$) gas laser was invented in 1964 and has one of the highest efficiencies of any known laser system. The subsequent invention of electron-beam-controlled $CO_2$ lasers at the Los Alamos Scientific Laboratory in 1969 provided the key to scaling up short-pulse $CO_2$ lasers to the size required for laser fusion research. Our Laboratory quickly became a leader in the development of $CO_2$ lasers for fusion research, having begun laser-target experiments in early 1973 on the Single-Beam System. The first fusion reactions ever initiated by a $CO_2$ laser were produced on the Two-Beam $CO_2$ Laser System at our Laboratory (Fig. 3) in early 1977.

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*One nanosecond equals a billionth of a second.

**One picosecond equals a trillionth of a second.

†One megajoule equals a million joules.

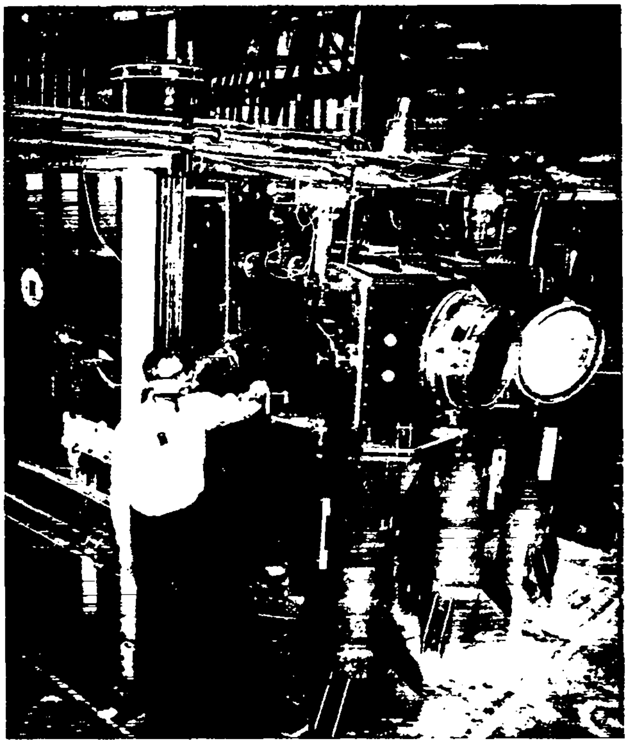

*Fig. 3.*

Helios, an eight-beam $CO_2$ laser system, was completed in April 1978 and has exceeded its design goal of producing 10 kilojoules* of energy within 1 nanosecond. Helios operates at an electrical efficiency of about 2%. Its goals, in the target experiments now under way, are to achieve high fuel compressions with the aim of developing prototype targets for the demonstration of scientific breakeven (when the energy released by the pellet fusion reactions equals or exceeds the laser pulse energy that strikes the pellets). A 100-kilojoule system, named Antares, will begin operation at our Laboratory in 1983. Its goal is to actually demonstrate scientific breakeven, which would be a significant milestone in the National Laser Fusion Program.

Early in the National Laser Fusion Program, it was thought that the infrared wavelength of invisible $CO_2$ laser light made it unsuitable for fusion, but both theoretical and experimental studies have shown that the expected detrimental effects do not occur. The issue was resolved in early 1977, when $CO_2$-laser-induced fusion reactions were observed on the Two-Beam System at our Laboratory. Fusion results were found to be quite similar for 1.06-micrometer** (Nd:glass) and 10.6 micrometer ($CO_2$) laser wavelengths.

## Theory and Experiments

The interaction of laser light with fusion pellets must be completely understood, so that pellets may be designed to provide maximum energy release. In our studies, we must understand and exploit physical phenomena occurring in nature only in the sun and other stars. Therefore, there is close cooperation in theoretical efforts to understand the underlying physics, pellet design, and experimental work. The focus of laser fusion research in the 1970s has been to perform both simple and complex experiments, allowing theorists to confirm their theories and to guide the development of new models of important physical processes.

An essential aspect of this experimental work is the development of instrumentation to diagnose the physical processes occurring in laser-target interactions. The desired experimental observations include the time behavior, quantities, and energies of charged particles (ions and electrons), neutrons, and light (x rays, visible, 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 of our diagnostic instruments be developed for our specific applications. For example, our Laboratory has developed the fastest detector in existence, an x-ray streak camera.

## Pellet Fabrication

Typically, pellets for laser fusion research consist of DT-filled spherical glass microballoon shells 100 to 200 micrometers in diameter with 1-micrometer-thick walls. (Figure 4 shows a microballoon on a human hair.) These microballoons may be used individually or may be nested to make multiple-concentric-shell pellets. The center of the pellet is filled with DT gas at several atmospheres pressure or with a spherical shell of DT ice. Fabrication of

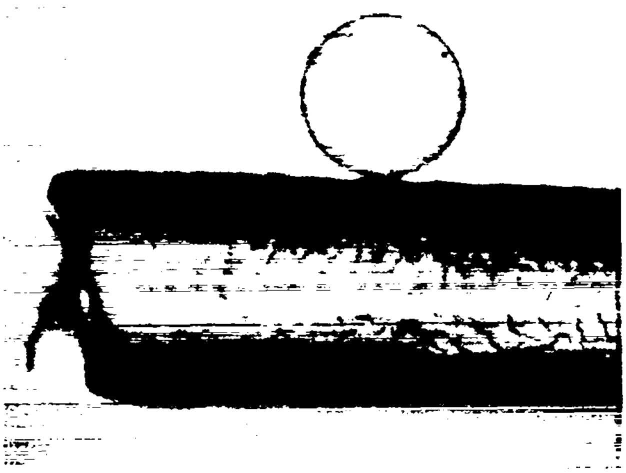

*Fig. 4.*

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*One kilojoule equals a thousand joules. A 100-watt light bulb uses 1 kilojoule in 10 seconds.

**One micrometer equals a millionth of a meter, or ~0.000 04 inch.

these pellets for experimental purposes is a very meticulous process because only one commercial glass microballoon in a million has the correct size, shape, and strength. Batch processes, followed by individual examination, are used to sort the microballoons. Final preparation involves machining and mounting these small pellets. The gas is then injected and sometimes frozen into DT ice. Fuel pellets for commercial power production will be larger and, of necessity, mass produced.

### Systems Studies and Reactor Design

Systems studies play an important role in any long-range program aimed at commercial applications. They consider the large picture of laser fusion—defining and analyzing the ultimate goals and the prudent pace of research and development required to reach these goals. Especially important are the conceptual design and analysis of commercial laser fusion systems of the future to ensure that the direction of our research and development is sensible from scientific, engineering, and economic viewpoints.

For example, the design of a reaction chamber to house the fusion reactions is a difficult technological problem. At only 10 laser pulses per second, the chamber must withstand 300 million pressure shocks per year, along with the microscopic damage induced by the pellet debris. Chamber design and analysis are proceeding so that the reactor design can be ready when the scientific progress in laser fusion permits a commercial demonstration. Present reactor design concentrates on minimizing the damage to the walls and using lithium and reaction products to produce the tritium for the fuel pellets. Related facets of the work are power generation cycles and systems for fabrication and insertion of the pellets into the reaction chamber.

## THE FUTURE

The crucial goals for commercial demonstration of laser fusion as an energy source in the early 21st century are:

- Demonstration of scientific breakeven, when the fusion energy released from a pellet equals or exceeds the laser light energy focused onto the pellet (early 1980s).
- Operation of a Materials Test Facility to demonstrate the repetitive operation of a laser fusion facility and to test possible materials for commercial laser fusion reaction chambers (late 1980s or early 1990s).
- Construction of an Experimental Test Reactor to test at the required repetition rate all subsystems for commercial laser fusion including an efficient laser system, a pellet fabrication facility with tritium manufacture, and the heat exchange and transfer system with steam production (mid 1990s).
- Finally, construction of a Demonstration Plant such as the one in Fig. 5, which could deliver over 1000 megawatts* of electricity to consumers (enough to support a city of a half million people) and permit detailed economic analysis of the performance for later commercial plants (early 21st century).

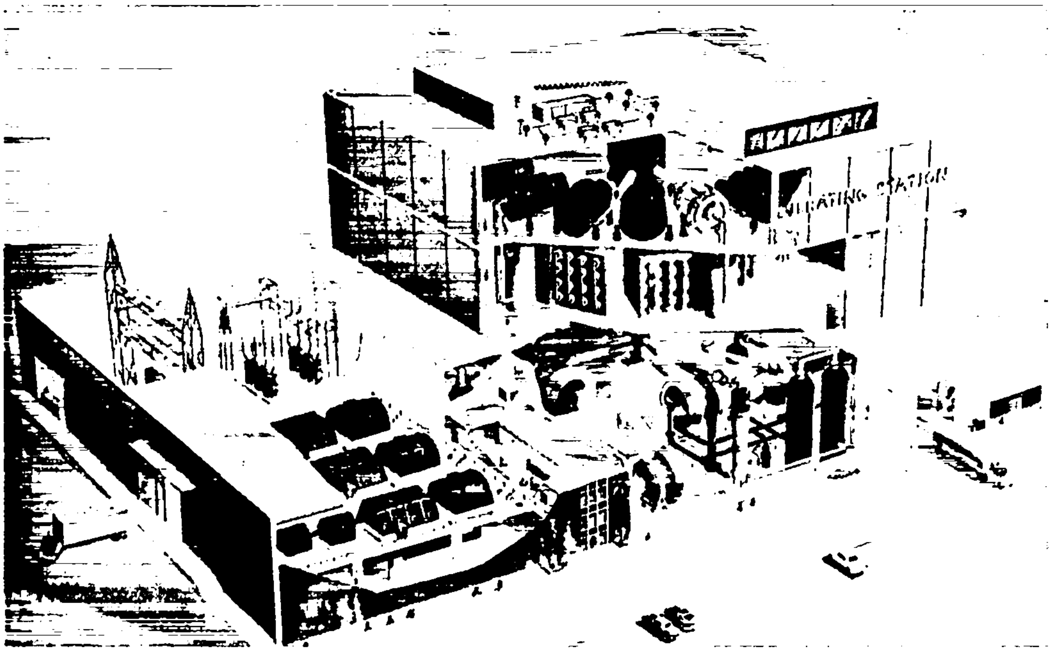

*Fig. 5.*

Mini-Review
readers are encouraged
to correspond directly
with the author.

For further information on laser fusion, request a copy of "The Potentialities of $CO_2$ Lasers For Inertial Fusion," by Roger B. Perkins, Laser Fusion Program Manager.

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*One megawatt equals a million watts.

☆U.S. Government Printing Office: 1978—