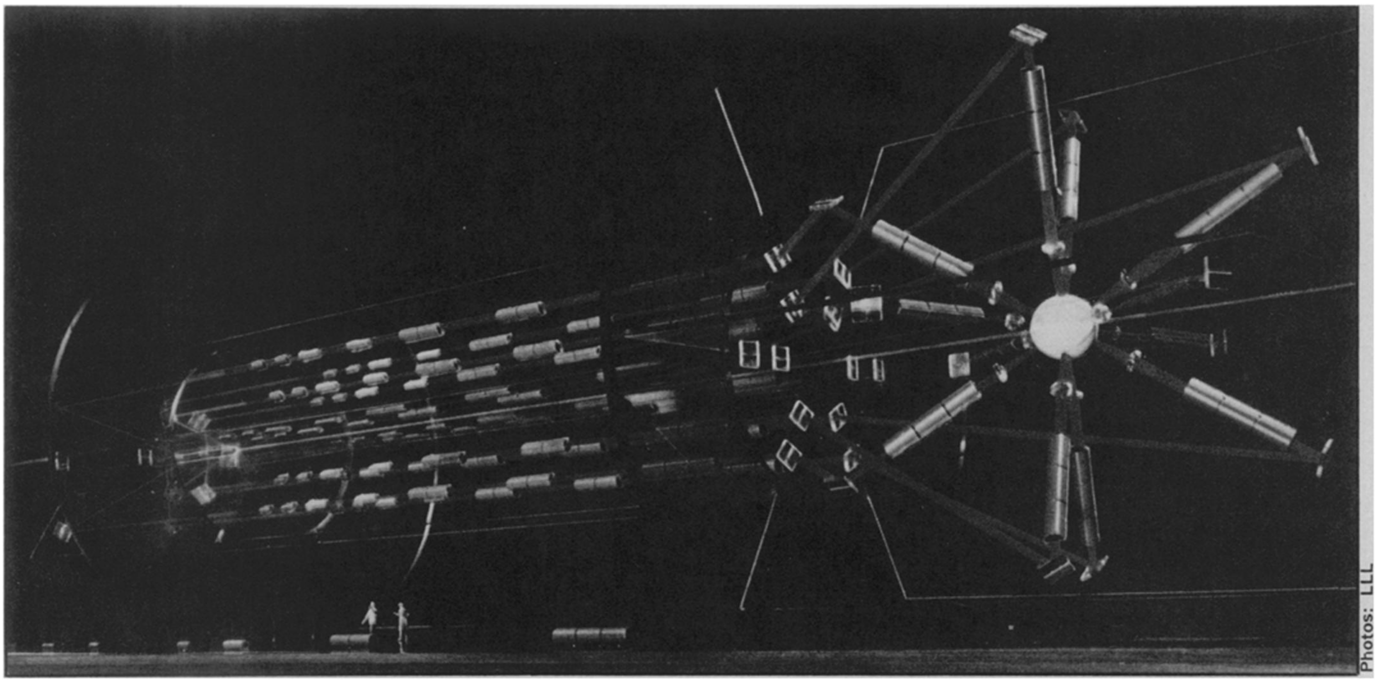
Laser Fusion

On the road to laser-fusion power at Lawrence Livermore Laboratory

by Dietrick E. Thomsen



The 12-armed, 10,000-joule laser-fusion experiment modeled here is LLL's next major milepost on the road to power.

The fuel pellet is a tiny silvery globule, much smaller than the head of a pin. It hangs on the end of a whisker in a round chamber that is about the size and shape of a deep-sea diver's helmet, but has many more windows than a diver's helmet. From a host of tiny pellets like this one, made of deuterium mixed with tritium, is expected someday to come electric power. The power would be generated by fusions of the atomic nuclei in the pellet ignited by bursts of laser light.

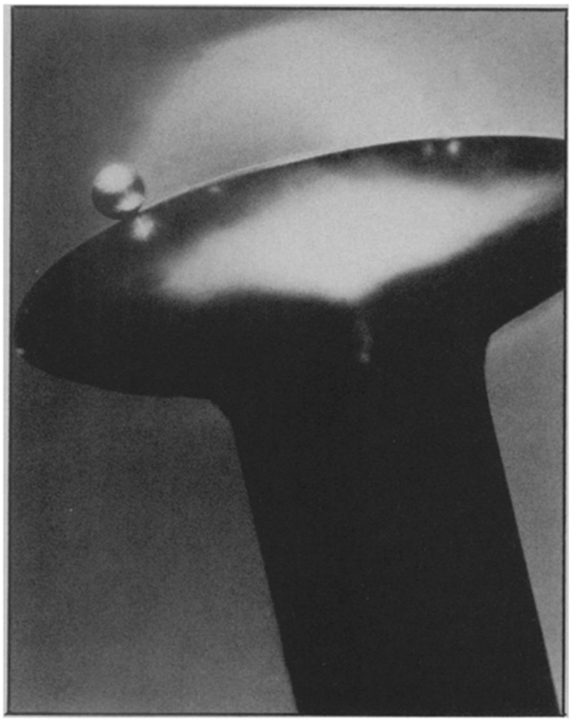
The pellet and the chamber in which it hangs belong to the Lawrence Livermore Laboratory in California, one of the two places where the U.S. Atomic Energy Commission is concentrating its laser-fusion money. (Los Alamos is the other.) Variously funded laser-fusion work is proceeding at other locations in the United States (the University of Rochester and KMS Industries in Ann Arbor), in the Soviet Union and possibly in other countries. LLL's effort is one of the biggest, and on the occasion of the 8th International Quantum Electronics Conference in San Francisco in June, it was both discussed and opened to visits by scientists and reporters attending the meeting.

Visitors were invited to peer at the fuel pellet through one of about 20 glass ports in the chamber. Ultimately the hope is that such a pellet, in a chamber perhaps like this, perhaps of some other design, will be irradiated simultaneously from all sides by 12 or 20 or however many you wish powerful laser beams. The light will first cause an ablation or evaporation of the extreme outer surface of the pellet. This in its turn will trigger an implosion of the pellet. The implosion will heat, ionize and induce fusions in the fuel. It will also serve to confine the fuel while enough fusions happen to produce a significant amount of energy. The energy will come away with energetic neutrons that can be used to heat something or with charged particles that can be collected and turned directly into electric current.

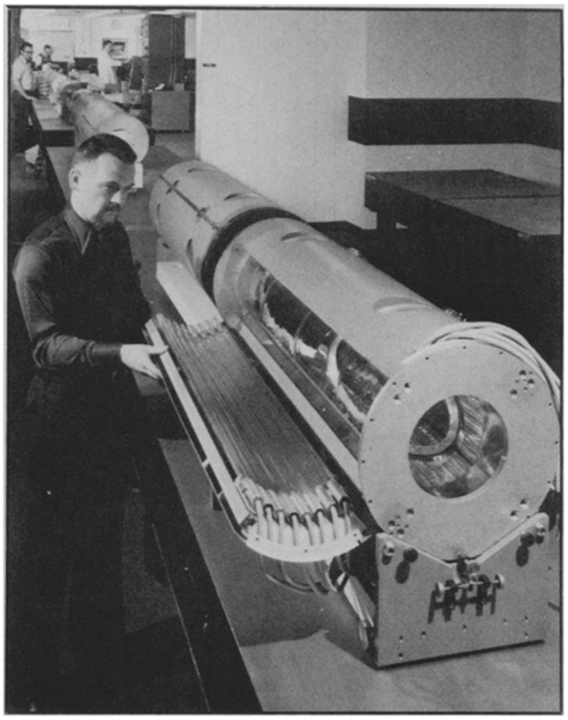
Right now only two of the many ports in the pellet chamber will be used to admit laser light. The others will be for various pieces of diagnostic equipment. The stage of the game at present, an experiment scheduled to start running in a few weeks, is a two-arm system in which the light from a laser will be split and amplified and brought into the chamber from opposite sides. The beams will each be 50 joules of energy in pulses one-tenth of a nanosecond (one ten-billionth of a second) long.

The purpose is to study exactly what happens when the light hits the target. A detailed knowledge of this "light-plasma interaction" is necessary for progress in the work. Theory makes predictions, but it is necessary to see what happens to theory in the nitty-gritty world of optical benches, laser amplifiers and deuterium pellets. A. Carl Haussmann Jr., associate director for plans and lasers, claims that the LLL experiment has better target diagnostics than competitors, and he indicates that they intend to know all they can about light-plasma interaction as they progress. This is not exactly square one in the game, but it's a long way from a hotel on the boardwalk too.

At the moment they are using the wrong kind of laser at the wrong wavelength for their ultimate purpose, and



One of the fuel pellets compared to a pinhead.



Krupke displays the innards of a laser amplifier.

they cheerfully admit it. LLL is working mainly with solid-state lasers, particularly neodymium-glass. Los Alamos is concentrating on gas lasers, though LLL has a small gas-laser program.

It will probably be a highly efficient gas laser that will do the job in the future fusion machine, Haussman believes. A solid-state laser will never do because its amplifying material, being solid, heats up and must be periodically cooled. It will never stand the 10 to 100 pulses per second required. Neodymium-glass lasers are also inefficient, but they happen to be versatile and better known than other varieties. Thus they offer the opportunity of starting with an instrument that is fairly well understood to investigate the unknowns of the light-target interaction.

What is needed for the future is an efficient gas laser. The most efficient gas laser now known uses carbon dioxide as the lasing substance. Los Alamos will study carbon-dioxide lasers (and so will Livermore to some extent), but in the end carbon dioxide is not the way to go either. The carbon-dioxide beam is in the infrared at a wavelength of about 10 microns. The ultimate fusion laser, theory indicates, ought to produce visible light of a blue-green color. Haussmann says John Murray has developed a new laser medium that uses a chemical reaction between atomic oxygen and xenon oxide to produce lasing. This is blue-green light and would be an "ideal laser." How it will develop remains to be seen.

Meanwhile glass lasers will be used in the next major step, for which a new building is being built. "The technology of the solid-state glass laser is the most advanced and well understood of all the laser devices," William Krupke, an associate division leader at LLL is quoted in the LLL publication Newsline. "If you're setting out to prove the feasibility of the laser-implosion concept, it's the kind of laser you want." Feasibility is what they intend to prove first. A working reactor is still many years down the road if possible at all.

The next step toward a proof, for which components are being assembled now, will irradiate a target from 12 or maybe 20 sides with a total of about 10,000 joules of energy, 60 times as much power as any laser that exists today. Plans are to have it running by 1977.

Twenty arms may prove more attractive than 12, says Haussmann, because the experiment can be shorter, and one amplifying stage can be omitted. Six or seven amplifiers are needed to bring each arm of the experiment to an energy about 1,000 joules in pulses ranging from tens of picoseconds to tens of nanoseconds. The whole array

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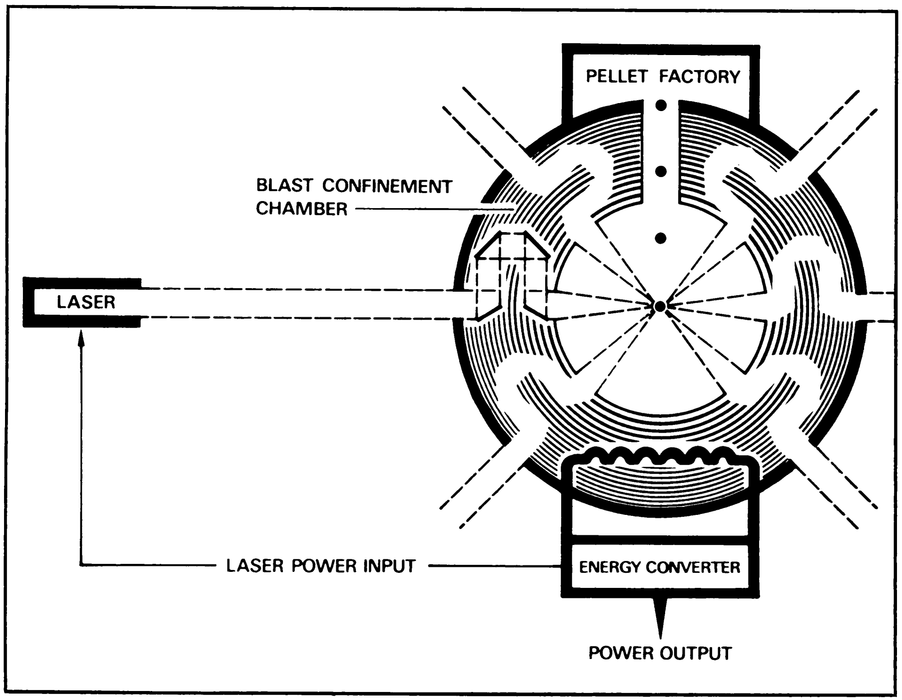

Schematic of the components of a possible future laser-fusion power reactor.

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will be three stories high and about 200 feet long.

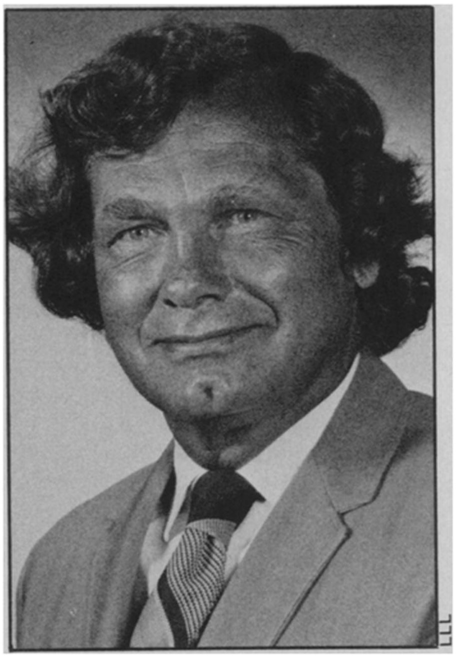
The basic elements in the amplifiers are elliptically shaped glass disks. Doping with neodymium gives the glass a transparent purplish color. The disks are positioned at an angle (the Bragg angle) to the axis of the light beam so as to suppress internal reflections in the glass, which can start energy-robbing modes of vibration. Around the glass disks is a bank of flashlamps. The whole is contained in a metal cylinder. As the light pulse comes into each amplifying section, the flashlamps flash. The glass disks take the energy they deliver—or at least part of it—and amplify the laser beam.

One of the most important things to be studied is the exact shape of that pulse. Instantaneous though it may be by any human standard, the pulse has a certain shape in space and time—light travels three millimeters in 10 picoseconds—and this shape crucially affects the way the energy is delivered to the target.

How to get a picture of such a thing? Your handy point-and-snap pocket camera won't do. While its shutter is flapping (assuming a hundredth of a second), a billion ten-picosecond pulses could fly by—that is, if they came end to end, which in pulsed lasers they do not generally do.

The apparatus that does it, is called a streak camera. (The term has nothing to do with running around naked, popular as that may have become lately.) This is truly a Russian invention. The first one was reported from the Soviet Union in 1968. Livermore's first model came shortly after that. It was a Rube Goldbergish thing, six feet long with a separate power package. Livermore engineers have now got it scaled down to a sleek unit that looks almost mass manufacturable. They have improved its performance too.

"Now we can get on film an accurate picture of the shape and width of otherwise invisible laser pulses that in some cases exist for only 10 trillionths of a second," says Lamar Coleman, who is head of the laser diagnostics group. "Physicists have calculated the best width and shape a laser pulse should have to produce a thermonuclear implosion," he says. "Our camera will tell the designers whether or not their lasers are generating this optimum pulse and will help them find out how to modify the hardware."



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Haussmann: Probably be a gas laser.

Pellet design is another crucial area. According to John Nuckolls, who leads the group involved in pellet design, the important principle involved in laser-implosion fusion studies is that compressing the pellet to 10,000 times its normal density takes only one percent of the energy that would be required to heat the material to its ignition temperature. "At such high compressions the fuel burns up before it can fly apart," he says, "so that the confinement problem which has plagued fusion researchers for 20 years is bypassed."

What happens in detail is that the pellet surface, heated by the laser light explodes outward. This produces a "rocket" reaction that implodes the core of the pellet. "Because the laser-heated electrons scatter during transit through the material exploding from the pellet's surface, the pellet implodes to a near perfect sphere even though it cannot be heated perfectly uniformly by the laser," Nuckolls points out. "It is due only to this rare, nearly miraculous property, that the rocket implosion is capable of compressing matter to super-high densities."

The first experimental pellets will be hollow spheres of deuterated plastic. Their size, shape and the thickness of their walls are all precisely specified. The pellets are mass produced, but then must be passed through special sieves and finally examined by hand and eye. "We may have to look at thousands of pellets to come up with say 20 that meet the requirements for the early experiments," says Clark Souers, who heads the group that is doing the fabricating.

The ultimate pellet will probably be a deuterium-tritium mix weighing about a milligram. Though it would release as much energy as burning a gallon of gasoline or exploding 50 pounds of TNT, it would not have the explosive force of those events because of its minuscule mass. "We're fond of saying that the kind of explosion we're talking about sort of has the force of a large firecracker," says Nuckolls. A power plant would use about 10 such fuel-pellet explosions per second.

But there's a long way to that goal. Regarding pellet fabrication, Souers says: "We're really operating in a technological vacuum. It's a whole new field." That comment could well express the attitude of people in every phase of the work. They give the impression of a group who are starting out on a path that is inviting and exciting and that they expect to pay off. Not only is the ultimate goal within the range of possibility; they expect useful technological fallout along the way. Improvements in laser design and energy, the streak camera, apparatus for precision manufacture of small pellets, even a rocket engine are among the suggested spinoffs. More may come. □

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form? A utilitarian set of values that put a price tag and a cost-effectiveness calculation on everything? A humanitarian liberalism which seeks support for a full life for everyone and recognizes a new *obligation* of the dead to help the living?

Institutions will have to adapt to these new technologies and new demand for participation by resting such decisions not in an individual physician, but in committees made up of several health professionals who will have to base their ruling on publicly stated criteria; or, much better, in committees that include clergy, humanists, community leaders, citizens-at-large, who review these matters and set guidelines within which individuals could come to their decision. The courts, quite properly, would serve as a review and dialogue level for decisions passed by committees and individuals.

Finally, society, as it has already begun to do, will have to invest some time for a grand debate on all these matters. It is only in this way—through talk shows, symposiums, dialogues in coffee houses, places of worship, over dinner tables, even cocktail parties—that we slowly come to terms with a new issue, overcome our old-fashioned sentiments and form new ethical criteria. While the grand debate may seem at times repetitive, going nowhere, and conflict-ridden, in effect, there is no more economical way for a society to reset its taboos nor a better investment of a society's attentive capacity. Actually, having found our capacity to deal with these matters, having developed our ethical and participatory talents here, we may even carry them into other areas in which no basic reforms will come about without our active interjection. The questions of who shall live and when to let die are a quite suitable place to start our more ethically active existence. □