Ambitious Energy Project Loses Luster

Laser fusion, touted as a new energy source, has produced only fizzles; its military implications now predominate

Last month, for the first time, the Administration decreased research funds for one of the most exotic energy technologies on the books: laser fusion. The action did not stand out among the much deeper cuts to better known programs. But laser fusion was one of the favored energy programs of the 1970's and also a program with potential military applications in the defense-conscious 1980's. In that light, its abrupt reduction after years of steady increases was notable.

Laser fusion sprang from the world of strategic weapons research almost a decade ago to become a strong contender among future energy technologies. With the strong support of the national weapons laboratories, the program steadily grew to a level of expenditures over $200 million per year in the United States, with additional commitments abroad. The concept was that high-powered lasers directed at small hydrogen pellets could ignite tiny fusion explosions rapidly enough to be used as a commercial energy source, providing near-inexhaustible energy supplies. The Soviet Union moved aggressively to pursue the concept, and England, France, Japan, and others followed suit. Each country built lasers as big as it could afford to test the viability of the idea.

After a decade of research, laser fusion has suffered a number of setbacks. Not nearly as much progress as hoped for was made during the 1970's, and the program is falling out of favor in some quarters of Washington. The Office of Management and Budget (OMB) and parts of the Department of Energy (DOE) are questioning the program, while the House Armed Services Committee, which has jurisdiction over the program on Capitol Hill, is moving to protect the laser fusion effort. On 8 April, for instance, the committee restored the deleted funds and added a cost-of-living increase for fiscal 1982, bringing the funding to $236 million. The tug-of-war over funding is likely to continue, but it is clear that the program's direction has changed. For reasons rooted in its scientific status, laser fusion is now headed on a course that reemphasizes basic research, reduces its importance as an energy option, and may return it to the veiled world of classical research from which it originated.

Some say that the military applications have always been the primary goals of the program. "There are no changes, it has never been anything but a defense program," says a key staffer at the House Armed Services Committee. Although the publicity about laser fusion over the last decade has almost all been for its energy applications (sometimes with a footnote or a phrase about military spin-offs), there were earlier statements about military priority too. In 1975, the then-head of weapons activities at the Atomic Energy Commission (AEC) said that "what we are doing now, developing basic laser technology, is equally applicable to military and civilian aspects. But really this is a military program and it always has been." The statement of purpose is not very different from that of the program managers today.

The acting head of the Department of Energy's office supervising laser fusion research, R. L. Schriever, says that the energy aspects look tougher now, "and it will take a lot more work to get there." According to Schriever, "It can be argued that the energy goal of the program is being put on the shelf. But it is more fair to say that we are setting aside either application—civilian or military—for the goal of proof of scientific feasibility." He estimates that the "fork in the road" at which substantial funds must be committed exclusively to one purpose or the other lies at least 10 years away.

The outward indications of the military side of the program are much more prominent than before. In years past, the congressional budget hearings for laser fusion were open, well-attended events, but this year the principal hearing was a closed-door, classified briefing with no part open to the public. Another sign of change was that the DOE budget had no separate line for the program in the body of the document, but listed it as an undifferentiated part of the $1,162 million spent for weapons research, development, and testing. Finally, there is a battle between the OMB and the Congress to eliminate the formal trappings of the Office of Inertial Fusion and return its budget and staff to the DOE directorate of Defense Programs.

Combining two of the most exotic technologies of the 20th century, high-powered lasers and the physics of thermonuclear explosions, laser fusion was a solution in search of a problem until the energy crisis came along.

It was developed at the AEC's brash California weapons facility, the Lawrence Livermore Laboratory, and after the concept emerged from the cover of nuclear secrecy in 1972, the national program for laser fusion grew rapidly. The novelty of the laser had not worn off and fusion was an attractive high technology. As an energy source, it offered special practical advantages over the more arcane magnetic approach to producing energy by fusing two hydrogen nuclei, especially the flexibility to be built in smaller-sized plants. As a technical accomplishment it offered the seemingly magic possibility of combining two potentially destructive technologies into one with constructive purposes. As an R & D option, it offered the hope of leapfrogging the slow, tedious progress of the magnetic fusion program (that began in 1952) and taking the lead in a race to prove that the energy processes of the sun could be conquered and used in a controlled way.

During the 1970's, more than $1 billion was spent on laser fusion in the United States alone, and much was learned. What the results add up to is that laser fusion will almost certainly not be small in scale, it may never be useful as an energy source, and whatever its prognosis for success it is certainly far behind magnetic fusion.

"I never believed the statement about leapfrogging magnetic fusion and I don't believe it now," says Nobel Laureate Hans Bethe, who was a major figure in the development of the H-bomb and has been a close observer of fusion research for three decades. "Magnetic fusion is way ahead, at least 5 years and maybe 10," he observes.

One reason that magnetic fusion is ahead is that the coupling of the laser

0036-8075/81/0501-0517$00.75/0

beam (or beams) to the pellet has not occurred as expected. "Laser fusion has not achieved its goals," says Bethe. "Compression of the pellet is very difficult." The big lasers that were built in the 1970's did not achieve their goals of "breakeven" (defined as net energy gain), and now lasers 30 to 100 times larger are on the drawing boards. Once laser fusion advocates talked of lasers that could fit into a garage igniting microscopic pellets to produce energy in a community-scale power plant. In contrast, the next laser that the Livermore laboratory plans to build will be the size of a factory and the pellets will be far from microscopic. (In 1974 when a small company named KMS Fusion was for a year or so in the improbable position of being the world leader in laser fusion research, its lobbyist walked around Washington leaving behind samples of microsphere pellets so small that 10 million fit into a medicine vial.)

The abandonment of microscopic pellets (which couldn't be made to compress sufficiently) has meant that laser fusion is no longer a technology based on thermonuclear explosions the size of firecrackers, as its advocates liked to say. According to Edward Teller, father of the H-bomb, patriarch of the Livermore laboratory, and sometime critic of the laser fusion program, the size of laser fusion's thermonuclear explosion will be equivalent to "1 ton of TNT or not very much smaller." The force of a ton of TNT is approximately four times larger than the worst accident that the Clinch River Breeder Reactor is designed to withstand. There was testimony from an AEC official that still smaller "core disassembly accidents" would break the seals of the test breeder facility in Washington State if they were to occur. Devising a laser fusion reactor to sustain such an explosion even once could prove quite difficult. So the progression toward bigger lasers igniting more powerful pellets during the past decade of laser fusion research has undermined the hopes for small power plants and raised many questions about whether they would be workable at all.

As compression of the pellet with laser beams proved more and more difficult, the Office of Laser Fusion began to look for other high-powered beams to serve as fall-back options. Electron beams had received a small amount of support for work at Sandia Laboratories in New Mexico. It also considered light ion beams, heavy ion beams, and even advanced types of lasers, and started giving each substantial support in the late 1970's. To reflect this broadening, the program was renamed the Office of Inertial Fusion, after the pellet explosion concept (fusion confinement by inertial effects) rather than the type of "driver." Over 70 percent of the support continued to go to lasers, however, particularly to the large lasers being built at Livermore. By universal agreement, glass lasers of the Livermore type were fine for "one-shot" experiments, but could never be extrapolated to a commercial power plant.

As progress proved more problematic, the program stopped emphasizing milestones on the road to reactor development. The history of the breakeven milestone is a good example of what was happening. In the first major publication after secrecy was lifted in 1972, two scientists from Livermore, John Nuckolls and Lowell Wood, projected that breakeven-level experiments would occur during 1973 and that the next step, net energy production, would occur "sometime around 1975." No breakeven had been achieved by 1975, and the program managers officially projected it for sometime between 1979 and 1981. In the next 3 months, that schedule slipped by 2 years. By the time Livermore's large glass laser, SHIVA, reached full power in May 1978 the laboratory reported that breakeven was a milestone for future systems to achieve "in the mid-1980's." The latest program plans from the Office of Inertial Fusion in Washington have dropped all reference to energy milestones, showing instead pellet physics experiments through the mid-1980's.

Three large multibeam lasers were built during the 1970's, with the express purpose of achieving breakeven. The first tangible results came from KMS Fusion in 1974, and important work was done at other small lasers, especially at the Naval Research Laboratory in Washington, D.C. But the program was paced by large laser systems built at the Livermore laboratory, at the original American weapons laboratory, Los Alamos in New Mexico, and at the Lebedev Institute in Moscow. All of these big laser projects ran into serious difficulties.

The big Livermore laser, SHIVA, began working first. It and smaller glass lasers built before it at Livermore showed that there were some fundamental errors in the optimistic laser fusion calculations that had started off the decade. A 20-arm laser erected on a "space frame" in a cavernous bay, SHIVA showed that when intense laser light is shined on a pellet, the outer layer of the pellet does not simply blow off like a rocket and compress the rest. Instead an unexpected series of complex phenomena occur. Almost immediately the pellet surface turns into a mirror and reflects away a large percentage of the laser input. In addition, the surface interactions produce many "hot" electrons which heat the pellet from the inside out—much like a microwave oven heats a hamburger—and inhibit the compression. With less compression than was expected the pellets shot with SHIVA produced less thermonuclear energy than was expected and thus did not come close to breakeven.

What the Livermore group did achieve was a series of impressive technical successes in solving the development problems of building such a large laser (each beam is 20 centimeters in diameter). It also achieved pellet compression of 100 times liquid density. For useful laser fusion experiments, compression of at least 1000 must be reached. The next laser Livermore hopes to build, NOVA, would be 30 to 40 times more powerful and would cost $250 million. One stage of NOVA is funded so far, for $137 million.

The big Los Alamos laser, HELIOS, is a gas laser which has a longer wavelength than the Livermore laser. Calculations have indicated that the hot electron problems Livermore found were even worse with a long-wavelength laser, and none of the Los Alamos experiments contradict that finding. The first phase of the next Los Alamos laser, ANTARES, is under construction for $62.5 million. Los Alamos has had a management shake-up in its inertial fusion program recently, and researchers there hope that perhaps special pellet designs matched

Development of basic laser technology "is a military program and it always has been."

to the needs of their carbon dioxide lasers will solve the long-wavelength problem.

The Soviet program seemed on paper the most impressive of all, featuring a 216 beam laser. Although it was intended to be quite powerful, the big Soviet laser was under-engineered and beset with technical problems. As it was designed, the glass laser medium was driven too hard. U.S. laser builders warned the Lebedev Institute researchers there might be a problem, but the design went ahead. The result was that the operation of the laser produced severe damage to the glass rods in the laser, as well as to the windows and coatings of the system. According to one American laser builder, the Soviet laser just "chews rods up." Few results have come from the facility and the Soviets have reportedly given up on getting full power from their multibeam machine. A second type of laser at the Lebedev Institute has also run into difficulties. Thus, the large Soviet program gives no more grounds for optimism than the American program. It was held up as evidence of worldwide momentum in laser fusion research in 1973–1974, but in fact the Soviet effort has been a failure.

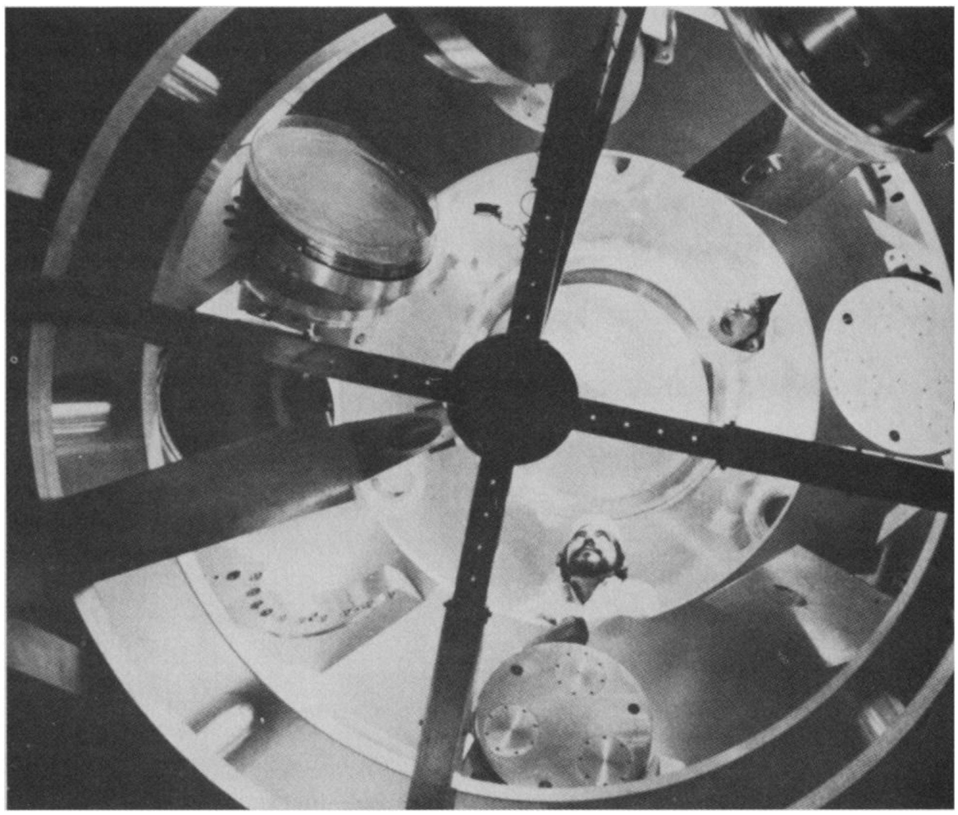
In addition to the weapons laboratories, KMS and the Naval Research Laboratory, there is also laser fusion research going on at the University of Rochester, where the founding director of the laboratory just left last month. Sandia laboratory has largely shifted its efforts from electron beams to light ion beams. Research on heavy ion beams, done at three accelerator laboratories, Lawrence Berkeley, Argonne, and Brookhaven, is a small and dwindling part of the overall effort.

The result of worldwide efforts is that laser fusion is in trouble from almost every standpoint. "Much less was accomplished in the 1970's than was expected," says Livermore scientist John Nuckolls, one of the foremost pellet designers and author of the 1972 paper that brought laser fusion into the light, "because there was too much competition and too few physics experiments." In his 1972 paper, Nuckolls predicted that breakeven could be achieved with a 1 kilojoule laser. These estimates were revised upwards in the mid-1970's, but not nearly enough. Now Nuckolls has raised his estimate to 300 kilojoules, with a substantial high-side margin of error. He and many others in the field would not be surprised now if it took 1 megajoule.

The commercial side of laser fusion has also been full of unpleasant surprises. A design for a laser fusion reactor made at the University of Wisconsin found that the small flexible reactor of the early 1970's had metamorphosed into a 15-story, 12-beam laser factory producing as much power as a nuclear plant. With huge laser beams focused by 11-foot mirrors, it would be a near-inexhaustible source of energy "although not necessarily a cheap one," according to one of the study authors. Another study of laser fusion practicality, done for the Electric Power Research Institute, and headed by the scientist who was behind the success of KMS, Keith Brueckner, found an interesting tidbit about power plants that others had managed to overlook: commercial units would produce 10 to 60 tons of radioactive waste per year just from unburned pellet debris. Brueckner, along with a number of others, advocates using heavy ion accelerators rather than lasers as the driver. Heavy ions apparently circumvent many of the pellet coupling problems of lasers. Whereas a "breakeven" scale laser might cost $0.5 billion, a comparable heavy ion driver would cost $1 billion. Such a heavy ion machine would be huge: estimates range from 1 to 9 kilometers in size for the three leading candidates.

Whichever way one looks for solutions to the problems laser fusion has encountered, it appears that the concept has lost those aspects that originally made it most attractive as an energy source. The Office of Inertial Fusion has largely stopped funding explicit reactor studies.

Laser fusion grew rapidly because of its potential as an energy program, and now the primary justifications and near-term goals are being stated in terms of its military applications. Were the energy benefits touted too strongly? The Livermore scientist who shepherded the program along during the 1960's long before it went public, thinks so. "From the standpoint of the politics of big science I can understand how that aspect was emphasized," says Ray Kidder who put together a 5-inch diameter glass laser for fusion experiments in 1968–1969. "But from a technical viewpoint, it was overemphasized," he says.



Los Alamos Scientific Laboratory

Los Alamos scientists propose a laser fusion experiment

Bethe at Cornell does not disagree. When asked if it was wise in hindsight to build up the laser fusion programs as fast as was done, Bethe replied that "you can read my conclusions from the statement that 'I always thought that magnetic fusion should get the major share of the funding and I still think so.' "

—WILLIAM D. METZ

The author, an energy consultant in Washington, D.C., is a nuclear physicist and former staff member of Science.